ENDEAVOUR

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Sound

At a time when atomic physics captivates both professional and lay attention, it is opportune to note that in no branch of science has technical development in recent years been more remarkable than in sound. Thirty years ago sound, which earlier, under the influence of British scientists like Tyndall and Rayleigh, had been a popular study, was a neglected subject in the universities, and one which, in spite of the gramophone and the telephone, was not very much cultivated in commercial laboratories. Today, largely owing to the importance of the cinematograph and broadcasting industries, the study of mechanical vibrations produced by and producing electrical and optical effects, and the investigation of the effects of air-borne vibrations upon the human ear in a great variety of circumstances, have created a body of ordered knowledge, comprehended under the general title of 'sound,' which forms a noteworthy part of modern physics.

The reproduction and recording of sound are now governed by a precision of calculation and design which has been made possible by the introduction of mathematical methods originally worked out for electrical circuits carrying alternating currents. An essential feature of any apparatus of the speaking or receiving type is a diaphragm or similar membrane whose vibrations are governed—forced, to use the technical term—by quickly varying forces, and it is of prime importance that the diaphragm shall follow faithfully. The forced vibrations of a mechanical system made up of diaphragms loaded in various ways are now investigated in terms of properties borrowed, in virtue of a close analogy, from the electrical circuit, so that conceptions such as impedance, long familiar in electrical calculations, are freely utilized in the case of mechanical vibrations. In place of tentative empirical methods we have accurate calculation which enables the performance of a given arrangement to be predicted, and results in a perfection of achievement exemplified by the very high fidelity of sound reproduction that characterizes the best modern instruments. The technique of modern alternating current circuits is, of course, applied directly to the problem, as well as indirectly, through mathematical analogy. With two 'speakers,' one for high frequencies and one for low frequencies, and with suitable electrical circuits to ensure that each one deals only with the range for which it is adapted, astonishing results can be obtained. This is but one aspect of the new methods comprehended in the term 'electro-acoustics,' which not only indicates the combination of electrical and mechanical apparatus but also the methods by which masses, restoring forces represented by springs and the like, and mechanical resistance find their analogies in electrical terms.

An extension of these studies is represented by new methods of reproducing and recording, unknown thirty years ago. The use of a light-beam of rapidly changing intensity to produce, by the agency of a photo-electric cell, first of all electrical variations and ultimately sound, is essential to the speaking film. The sound-track is usually made by causing the sound to regulate the strength of a light-beam which acts on a photographic film. The means by which the regulation is effected are manifold, complicated, and curious. There is, however, a method of recording the sound as a light-track which requires no photographic development. In this, a device cuts away mechanically the thin opaque covering on a transparent film. The principle is simple, the achievement excellent; but the elaboration of the process was a complicated piece of work requiring the highest skill in the new scientific technique. The imprinting on a running steel strip, or on a running band impregnated with a magnetic powder, of residual magnetism varying in degree with the sound vibrations is another popular method of

recording and reproducing, exemplifying the invocation of still another branch of physics.

A further field which is now the subject of precise investigation instead of hazardous trial is architectural acoustics. No architect would (or should) now design a hall for speech or music without specialized scientific advice. The prevention of, and protection from, noise is another allied sphere in which advances have recently been made, and one of profound importance, for the appreciation of silence is not the least significant cultural effect of our state-aided services.

The whole subject of vibrations of frequencies much too high to be audible, the so-called supersonics (or ultrasonics, as some prefer to call them), is another recent development. That the application of electrical charges to opposite faces of a quartz slab suitably cut leads to stresses in the slab follows from Curie's discovery of piezo-electricity. This makes it possible, by applying a rapidly varying electrical force to a crystal, to maintain vibrations of a frequency of several hundred thousand a second, the frequency being that proper to the longitudinal vibrations of the extremely short bar constituted by the crystal slab. This steady production of extremely high mechanical frequencies has had important results in pure science, as exemplified by the discovery of abnormal absorptions and velocities of sound in certain gases, traceable to certain types of molecular vibrations, and by the discovery of effects on small living organisms. It has also had a variety of practical applications. The vibrations of a quartz ring, piezo-electrically maintained, have been used to control a clock which varies by not more than a couple of thousandths of a second per day. The detection of cracks in solids and of the setting points of cements represents quite another utility.

Not the least remarkable of technical advances is, perhaps, the invention of electrical musical instruments, in which the player governs directly, by one means or another, electrical circuits producing electrical oscillations which are finally made audible by being fed into a loudspeaker. The tone producer may, for instance, be a revolving wheel with teeth that move past an electrical pick-up and so excite a pure tone, which can be blended with other pure tones, harmonics, at the discretion of the player. With an instrument based on such principles the player can produce not only the effect of the stops of the classical organ, but can manufacture others for himself. He can produce any frequency, any loudness, maintain the note for as long as he likes, and build up any quality. Many types of electrical organ and electrical piano have been produced. The great virtuosos on such instruments are still to be formed and it is interesting to await the possible artistic developments.

Though many of the striking recent developments in sound are due to the technical laboratories of great industrial concerns, the basis of all the progress is to be found in the discoveries made by workers in pure science. To some of these discoveries, in the mathematical study of vibrations and in supersonics, we hope to devote articles in forthcoming issues of ENDEAVOUR.

Correspondence

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

THE PLACE OF SCIENTISTS IN THE COMMUNITY

From Sir Robert Pickard, *Chairman, Joint Council of Professional Scientists;* Alex. Findlay, *President, the Royal Institute of Chemistry; and* Sir Lawrence Bragg, *President, the Institute of Physics.*

Although, in the British Dominions no less than in Britain itself, great advances in scientific research and in technology have been made since the war of 1914–18, it is perhaps still doubtful whether our peoples have, even yet, acquired that appreciation of science and understanding of its potentialities which are the only safeguard of our industrial future. While the important part which scientific and technological research has played in our war effort may find a widespread recognition, it is not less necessary that scientists should make it clear that if our countries are to be able to

(*Continued on page* 141)

The electron microscope

SIR GEORGE THOMSON

So far, atoms have been abstract conceptions deduced from experiment. Within the next few years we may be able to say of them 'seeing is believing,' for the electron microscope—here described by Sir George Thomson—is likely to render them visible. The electron microscope has already made possible noteworthy advances in pure science and excites hopes of providing a tool of the highest importance in medical research.

The last few years have seen an important development in the centuries-old art of observing the very minute. This has come about in a curious way. The visual microscope, from the ordinary hand lens to the most powerful instrument used in bacteriology or metallurgy, acts on the following principle: light from the object is bent by means of lenses of glass or other transparent material in such a way that when it enters the eye it is spread over a much larger area of the retina than it would have been if the object had been viewed in the ordinary way at the least distance from the eye at which clear vision is possible. The light from each point of the object is focused on to one element of the retina which perceives it. The collection of illuminated elements forms an *image* which causes vision of the object, and the apparent size of the object varies with the size of the image. Exactly the same thing happens in a photographic microscope, except that here the final image is on the photographic plate which acts as a kind of artificial retina, fixing the image so that it can be studied at leisure. Now though the eye is sensitive to light only, there are other forms of energy which can affect a photographic plate and, provided they can form an image, might be used in a photographic microscope. In fact, ultra-violet light, which differs from visible light only in its shorter wave-length, has long been so used for a reason which will appear shortly. But the possibilities do not stop here; other sorts of radiation will serve. The requirements are these: firstly the radiation must form 'rays' and not spread more than a small amount, otherwise the effects from different parts of the object will get inextricably mixed and it will be impossible to see its shape; secondly, it must be possible to control the rays so that those from one point of the object come together at or near one point of the image. The first requirement rules out radio waves or sound, the second would make it impracticable to use X-rays. Electrons, however, fulfil both requirements, and the purpose of this article is to show how they are being used in place of light in microscopes of unprecedented power.

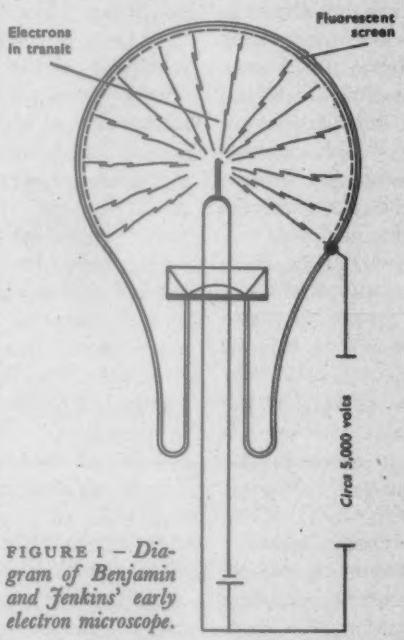

FIGURE 1 – *Diagram of Benjamin and Jenkins' early electron microscope.*

ELECTRONS

When an electric discharge passes through a gas at low pressure, rays leave the cathode or negative pole which can affect a photographic plate if they strike it, or can light up a fluorescent screen of (for example) powdered willemite placed in their way. These cathode rays are *electrons* and can be deflected by electric or magnetic fields. Some of the rays can be selected by letting them pass through a hole in a diaphragm inside the low-pressure region, and a fine beam can thus be formed. The cathode ray oscilloscope, an instrument which has found a thousand uses in the study of radio, makes use of the deflection of such a beam and is in fact an adaptation of the apparatus originally used by

Sir J. J. Thomson in his proof of the nature of cathode rays.

Electrons can, of course, be produced in other ways: they are emitted from a heated filament as in the ordinary radio valve, and can even be pulled directly out of a cold metal by very intense electric fields. However produced, they fulfil our requirements of going in approximately straight lines when not acted on by forces, and of being controllable by electric and magnetic fields.

A PRIMITIVE ELECTRON MICROSCOPE

The simplest form of electron microscope, though not the first to be discovered, is illustrated in figure 1, which shows the set-up used by the English scientists Benjamin[1] and Jenkins. Here the point of a wire is made to emit electrons which are accelerated by a radial electric field till they strike the surface of a bulb covered with fluorescent material. If, for example, one side of the point emits more electrons than the other, the corresponding side of the bulb will glow more brightly. In fact, the result is much better than this. Each small region on the point produces its corresponding patch of fluorescence, so that the surface of the bulb reproduces the emitting power of the different parts of the point of the wire; but since the surface of the bulb is enormously larger than that of the point, there is an enormous magnification. If the point were a small hemisphere the magnification would be the ratio of the radius of the bulb to that of the hemisphere.

The points used were of the order of $\frac{1}{100000}$ in. in radius, and the magnification was about 200,000. As is well known, a sharp point greatly increases the strength of an electric field, and with a point as fine as this a quite moderate voltage—under 10,000—is enough to pull electrons out of the wire by brute force, even though the wire is not nearly hot enough to emit them in the ordinary way. The effective part of the point turns out to be a single crystal of the metal of the wire, which was etched before use. Figures 6 and 8, kindly supplied by Dr Jenkins, show the kind of results which this instrument gives. The black patches show that there are certain regions which emit no electrons, and a study of their distribution in the light of the known crystal structure of the wire shows that they correspond to certain special crystal faces. It is probable that most of the emission comes from the edges where the faces join, and where the electric force is specially intense; but there is also a difference between crystallographically different faces. It also seems likely that, when the wire is heated, the mechanical forces on the surface due to the electric field are enough to pull out the edges between the faces into sharp *arêtes* even below the softening point of the metal, thus still further enhancing the concentration of field and intensifying the emission from the edges.

It is well known that the emitting powers of metals such as tungsten are much increased by a layer, only one atom thick, of the electropositive metals such as barium and thorium. This property is used to make 'dull-emitter' radio valves. Benjamin and Jenkins were able to study these changes by depositing small amounts of barium or thorium on the points of their wires and observing the changes in the fluorescent patterns so caused. Any part of the point which gets covered by the barium or thorium will emit more, and an increase in brightness will be seen on the part of the bulb corresponding to it. They were able to watch the foreign atoms migrating from the side of the point on which they were first deposited. The new atoms favour certain faces and edges of the crystal and avoid others. Surely it is one of the most remarkable achievements of experimental science that we should be able to follow in this way the movements and preferences of a few thousand atoms!

ELECTRIC LENSES

But though a most beautiful experiment, the uses of this device as a microscope are far too severely limited by its geometry and by the requirement that the surface shall itself emit electrons. The first restriction is lessened in the (earlier) apparatus of Brüche and Johannson. By passing a beam of electrons through a series of holes of varying size in two or three parallel screens maintained at carefully chosen electrical potentials, so that the electric forces round the edges of the holes pull the electrons from their paths, it is possible to make a beam which originally diverged from one point come together again and be focused on a photographic plate or fluorescent screen. The electrical field of the screens thus imitates the action of a convergent lens. In this way a magnified image of a small flat surface parallel to the screen can be formed and the electron emission from it studied. Many interesting results have been obtained. For example, it is known that the thorium atoms on a dull-emitter filament diffuse through the

[1] Dr Benjamin was unfortunately killed in an aeroplane accident while on Government service.

tungsten to replace the losses by evaporation from the surface. It used to be thought that the atoms found their way along the interfaces separating the small crystals in the tungsten wire, but it now appears that they go right through the solid, arriving at the surface in small patches unrelated in position to the crystal boundaries.

Most of the experiments of this kind have been done with relatively small magnifications of the order of 100. In the form in which we have described it, this instrument is limited to the study of surfaces which can emit electrons, i.e., in practice, metals. It is believed, however, that the Allgemeine Elektrizitäts Gesellschaft is developing an instrument to use electrostatic lenses with high magnification and an independent electron source, and similar work is in progress at the General Electric Company's laboratories at Schenectady, but it is doubtful if this kind of instrument will have any important advantages over the types developed here and in America, and now to be described.

MAGNETIC LENSES

It has been common knowledge for a long time that a beam of electrons travelling along the axis of a long cylinder, round which a wire is wound in a spiral, is kept together by the magnetic field produced when a current flows in the wire, the field acting as a rather peculiar convergent lens but without magnification. It has more recently been found by Knoll and Ruska that a short coil also can be effective, and indeed is more closely analogous in its action to that of a glass lens on light, being able to give a magnified image. Thus a magnetically controlled electron microscope becomes possible, and has certain practical advantages over the electric type.

RESOLVING POWER AND THE LIMITS OF USEFUL MAGNIFICATIONS

Before entering on the details of these instruments it is worth while considering what determines the effective limits of a microscope of any kind. Let us suppose, to make the question definite, that we are examining a specimen (such as that in figure 7) which has a number of small slits or spots. We want to see the spots singly and not just as a smudge. That is to say the light (or electrons) from each spot must be separated from the others, and brought to a separate place on the retina of the eye or the photographic plate without confusion with the light from any other spot. This is called *resolution*, and the resolving power of a microscope is its most important property. In a compound microscope the *magnification* is by stages, each stage viewing the image formed by the one before; but magnification without adequate resolving power is as futile as to enlarge a fuzzy photograph in the hope of seeing more detail. The eye can distinguish spots about $\frac{1}{100}$ in. apart (0·1 mm.), and if the finest detail we want to see is magnified up to this scale we have done the job, though to save straining the eyes it may be desirable to magnify by a small further factor, say 5. Now the magnification might in theory be repeated in as many stages as we like, and there would seem to be no definite limit to the fineness of detail which could be magnified up to $\frac{1}{100}$ in. and so made visible. But here resolving power comes in. If at any stage the rays from two spots get hopelessly mixed, nothing we can do afterwards will unmix them. The individuality of the spots is lost and they are indistinguishable from one larger spot. Clearly, resolution is hardest when the spots are closest, so it is the first lens, which looks at them before they are magnified, which is most likely to fail in this respect.

As is well known, light is a form of wave-motion, and this fact governs the least distance apart at which spots can be distinguished. If one drops a stone into a calm pond, the place it hits will become the centre of expanding circular ripples. An intelligent water-beetle on the surface could tell the direction of the stone from the way the waves struck him. If two stones were dropped at the same time some considerable distance apart he would experience a rather irregular motion, which would be like that of a cross-sea, but which he could perceive was due to two separate sets of waves coming from different directions (figure 2). If, however, the two stones strike closer together than about the distance between the trough and crest of a wave, their two wave-systems will fuse and our water-beetle, however intelligent, will only think that one rather large stone has dropped (figure 3). This is an instance of a general rule for all kinds of wave-motion, which says that the least distance between two spots which allows them to be seen separately is about half a wave-length. For visible light this is about 0·00025 mm. Now $400 \times 0{\cdot}00025 = 0{\cdot}1$ mm., the least visible distance. Hence a magnification of 400 will suffice to make visible the least distance that can be resolved. It

may be worth going to × 1,000 or even × 2,000 to make the picture easier to read, but the extra magnification is wasted in the sense that nothing real can be seen which could not with care have been seen without it. Certainly any further magnification is merely misleading. However, we may use ultra-violet light and liquid immersion, both of which shorten the wave-length at the object, which is what matters. In these ways one can push the limit down to about 0·0001 mm. or 0·1 μ to use a unit common in microscopy, and magnifications up to about × 5,000 are useful in favourable circumstances.

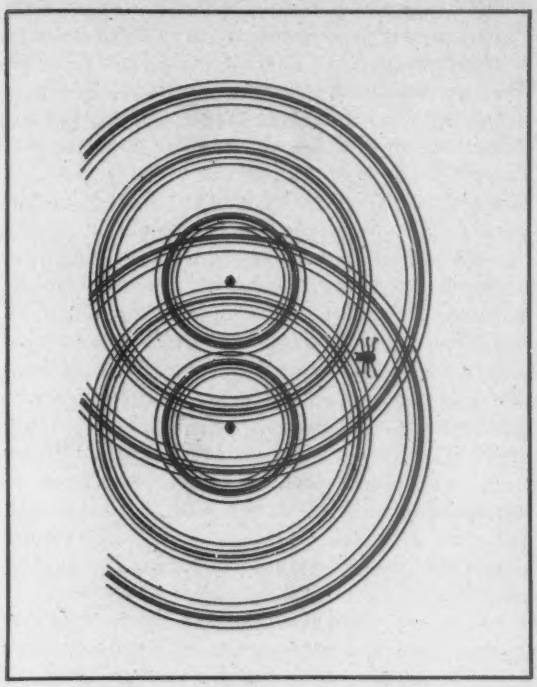

FIGURE 2

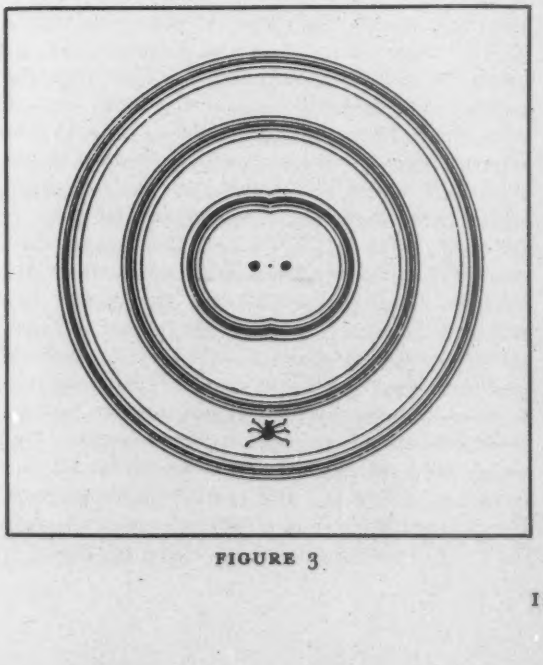

FIGURE 3

ELECTRON WAVES

Now how do electrons help here? Until fifteen years ago the answer would have been that if the electrons could be suitably handled there would be no lower limit, at least down to atomic sizes, because the electrons were thought of as particles much smaller than atoms. We now know that all particles, and in particular electrons, have a dual character, partly particle and partly wave. Without entering into the very difficult ideas involved it is enough to say here that, as far as resolution is concerned, electrons act like waves whose wave-length depends on their speed, the fastest electrons having the shortest waves. Slow electrons with a speed such as they would get by being accelerated from rest by a potential of a quarter of a volt, have a wave-length of about two millionths of a millimetre. Such might be the electrons at the moment of emission from a hot filament. Cathode rays with energy even of 15,000 volts have the truly minute wave-length of a one hundred millionth of a millimetre. These wave-lengths are much less than those of any usable ultra-violet light, are indeed no larger than those of X-rays, and allow a great increase in resolving power and useful magnification.

Actually things are not quite as favourable for the electron microscope as a crude comparison of wave-lengths indicates. The full resolving power can be achieved only if the lens can gather radiation coming from the object over a complete hemisphere. This is an unattainable ideal anyhow, but the best microscope objectives come fairly near it and take in a very wide cone of rays from each point of the object. With the electron microscope, at any rate with lenses of the existing types, it seems that what in an ordinary lens is called spherical aberration, which means a failure to form a perfect image for geometrical reasons, makes it necessary to use only a narrow cone of rays. This may give a factor of 100 or more against the electron microscope, but even so its theoretical resolving power with 15,000 volt electrons is about one millionth

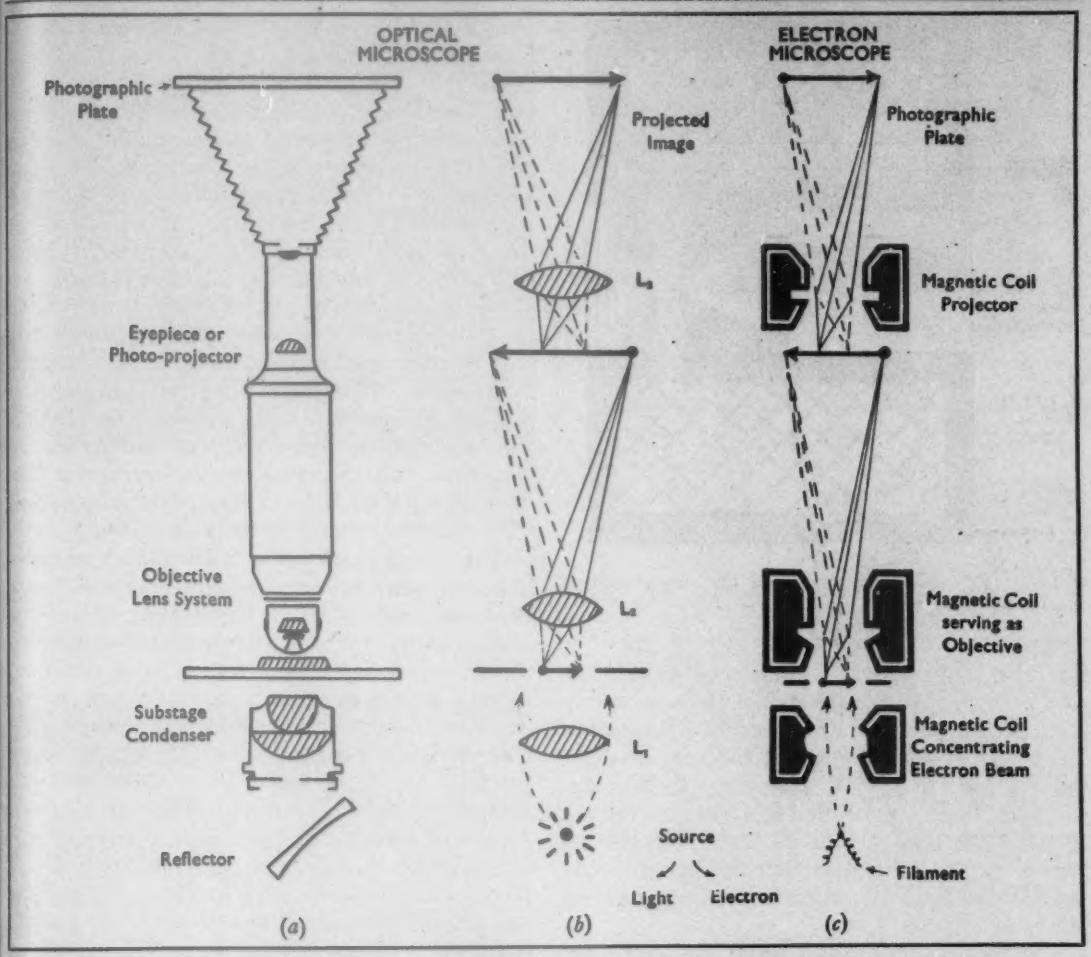

FIGURE 4 — *Comparison of light microscope and magnetic electron microscope.*

of a millimetre, or a hundred times better than the best obtainable with any probable use of ultra-violet light.

MAGNETIC ELECTRON MICROSCOPES

Instruments making use of these ideas to give very high resolving powers and useful magnifications have been developed in Belgium by Marton, in Great Britain at the Imperial College[1] and the National Physical Laboratory[2] with the aid of Metropolitan-Vickers, and in Canada and the United States. One of the most recent is that made by the R.C.A. Manufacturing Company, New Jersey, which incorporates a number of features developed by Professor E. F. Burton and his co-workers of Toronto University and is illustrated in figure 9.

The Toronto instrument, which resembles the above in its main features, is fairly typical of the newer practices. It stands about 5 ft. high and is exhausted to a very good vacuum by powerful pumps. The electrons are generated in a hot cathode and accelerated to about 45,000 volts. The electrons pass through the specimens, which have to be very thin and are usually mounted either on fine wire gauze or on a disc with a small hole in it. Three magnetic lenses are used, corresponding exactly to the condenser, objective, and eyepiece respectively of an ordinary microscope. How they are arranged is shown in figure 4, which shows each part of the electron microscope compared with the corresponding part of the light microscope,

[1] Professor Martin and others.
[2] Dr Preston and others in the Metallurgy Department.

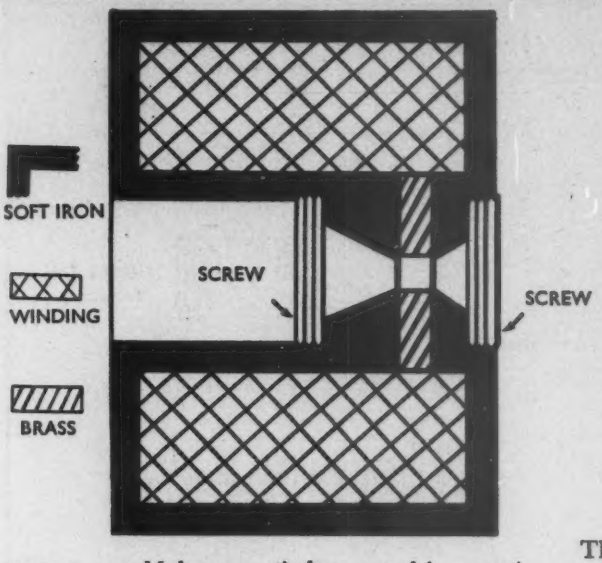

FIGURE 5 — *Modern magnetic lens as used in magnetic electron microscope.*

and how the paths of the electron imitate the rays of light. In the figure the electron microscope is shown with its source of illumination below and the final image at the top, for comparison with its optical analogue. In practice, the instrument is so tall that it is more convenient to have the source with its high potential up above out of the way, so that the figure should be reversed for comparison with the picture in figure 9.

The first-stage magnified image formed by the objective can, if desired, be thrown on to a fluorescent screen for adjustments to be made. The final image can also be viewed in the same way on a second screen, or the fluorescent screen can be removed and the electrons allowed to strike a photographic plate, where they produce a latent image which can be developed in the ordinary way.

The type of 'lens' now generally used is shown in figure 5. It is a short hollow cylindrical coil of wire, carrying a current and entirely enclosed in an iron sheath, except for a narrow brass ring on the inner surface. This brass ring interrupts the lines of magnetic force which tend to run in the iron, and forces them into the open. The thickening of the iron on each side of the brass narrows the hole here and increases the concentration of magnetic forces near this part of the axial line. Such a lens may have a useful focal length of about 5 mm.

With instruments such as these, magnifications of × 20,000, × 40,000, and × 60,000 are readily obtainable, and even one of 150,000 diameters is possible. What is, as we have seen, more important is the resolving power. The best estimates of this show that a resolving power of $\frac{1}{100000}$ mm. is readily obtained in practice, while under the best conditions results two or three times as good are possible, which is not too far below that predicted by theory. Even the lower value is ten times as good as in the best ultra-violet microscope. The images obtained are very sharp, and it is a good plan to use a fine-grained photographic plate and magnify the results visually about tenfold. The accompanying illustrations (figures 10–16) show a few of the results obtained on very varying kinds of specimens[1].

The R.C.A. instrument has a device to allow the specimen to be changed without letting down the vacuum in the whole instrument. It is most important that the lenses and the specimen should be adjustable with respect to one another, for no accuracy of manufacture can prevent slight asymmetries, and these become enormously magnified. To allow this to be done the instrument is made in six sections—one above the other. The top and bottom of each section are ground perfectly flat, and the joints made airtight with grease. The sections can be pushed slowly over each other by adjusting screws and accurately alined without spoiling the vacuum. It is also important to ensure that the inside of the camera is kept very clean and free from grease, which might become electrically charged and deflect the electron beam.

It is essential to maintain the voltage accelerating the electron at an extremely constant value. In fact, the 45,000 volts of the Toronto instrument are not allowed to vary by more than a single volt. To do this, of course, requires an elaborate electric installation, and use is made of radio technique. The reason for this extreme constancy is that electrons of different speeds are bent differently by the magnetic lenses, just as light of different colours is bent differently by

[1]Figures 13, 15, and 16 were taken with the Toronto instrument and are reproduced from *The Electron Microscope* (Burton and Kohl) by kind permission of Reinhold Publishing Corporation. Figures 10, 11, 12, and 14 were taken in the Metallurgy Department of the National Physical Laboratory and are reproduced by kind permission of the Director. The instrument used is indicated on each.

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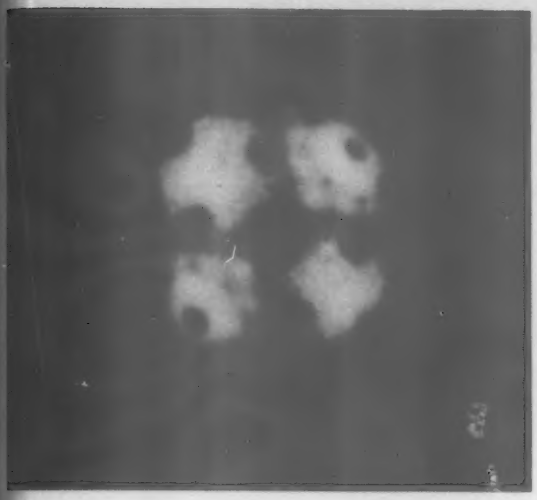

FIGURE 6 – *Emission from a molybdenum point, partially smoothed by heating for a short time to a high temperature. The black spots correspond to crystal faces.* (From Dr. Jenkins.)

FIGURE 7 – Diatom: Pleurosigma angulatum. *The shell of this small plant is pierced by a regular array of small holes. The structure is just beyond the resolving power of an optical microscope.* (×14,000)

(*Taken with R.C.A. instrument at the National Physical Laboratory.*)

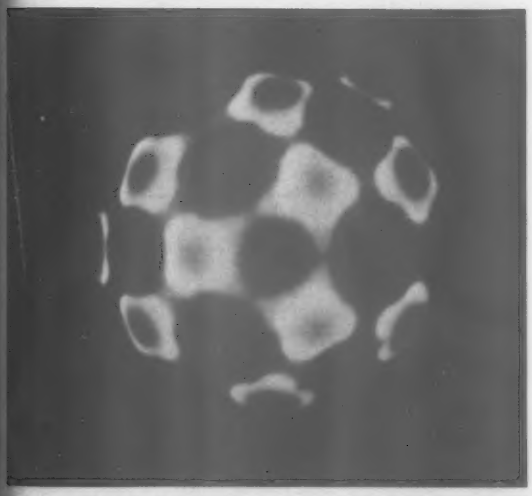

FIGURE 8 – *Emission from a nickel point heated to* 920° *C. The black regions correspond to crystal faces, the regions of emission to edges.* (From Jenkins.)

FIGURE 9 (*right*) – *An R.C.A. magnetic electron microscope.*

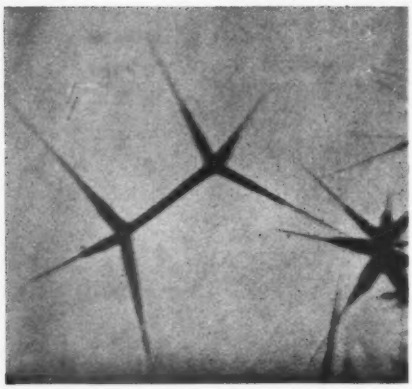

FIGURE 10 – Zinc oxide smoke, *produced by burning metallic zinc: consists of long needle-like crystals of zinc oxide.* (×ca. 7,000)
(Taken with Metro-Vic instrument at the National Physical Laboratory.)

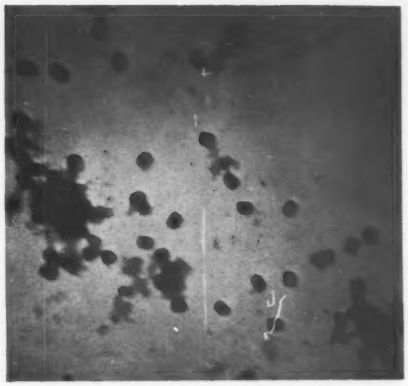

FIGURE 11 – Vaccinia. *The small oblong bodies are the active agent which produces immunity from small-pox.* (×10,000)
(Taken with Metro-Vic instrument at the National Physical Laboratory.)

FIGURE 12 – Bacteria: B. fluor
Some internal structure visible. (×
(Taken with Metro-Vic instrument at the National Physical Laboratory.)

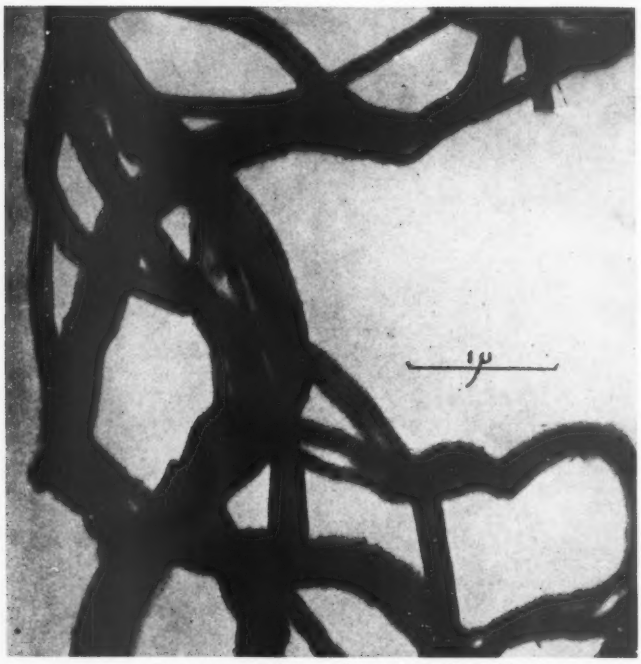

FIGURE 13 – Cuprene, *a polymer of acetylene, formed in the presence of copper.* *(Taken with the Toronto electron microscope.)* (×22,700)

FIGURE 14 – Aucuba mosaic virus. *The virus respon disease in tomato plants is seen to consist of long thread-like in this specimen prepared at Rothamsted Experimental Statio*
(Taken with R.C.A. instrument at the National Physical Laboratory.) (

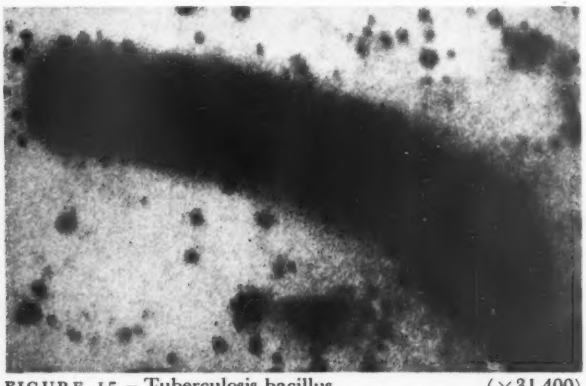

FIGURE 15 – Tuberculosis bacillus. (×31,400)
(Taken with the Toronto electron microscope.)

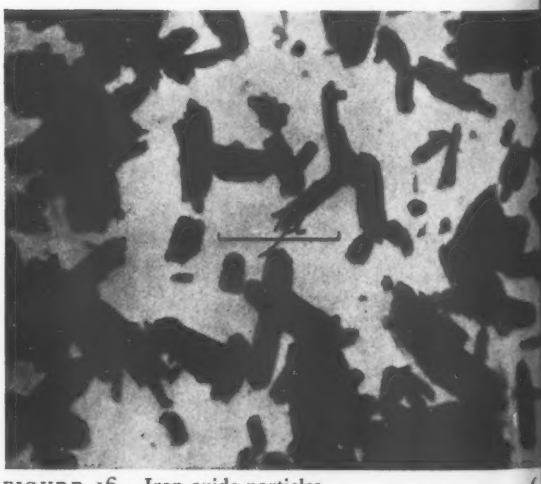

FIGURE 16 – Iron oxide particles. (
(Taken with the Toronto electron microscope.)

X

a glass lens, only more so. Thus if electrons of different velocities are present the images will be blurred and good definition will be impossible. It is also important to keep the currents in the magnetic lenses accurately constant, since on these depend their focal lengths.

SPECIMENS MUST BE THIN

The reader will have noticed that the electrons pass *through* the specimen in this type of microscope. Now electrons even of 45,000 volts energy have not much penetrating power; they would, for example, hardly get through tissue paper. But it is worse than this, for not only must the electrons get through the specimen, but they must do so without loss of speed, or the lens will fail to focus them properly for the reason we have just given. This reduces the permissible thickness to a few millionths of an inch if the picture is to show light and shade. Of course, a much thicker specimen can be used if all that is wanted is a silhouette of its edge or a picture of holes pierced in it (cf. figure 7), but in such a case the solid parts will appear completely black on a positive. Light and shade in a picture with the electron microscope, or indeed with an ordinary one for that matter, depend on differences in the scattering and absorption of the radiation by different parts of the specimen. In the case of the electron microscope a very small deflection is enough to turn the electrons out of the effective part of the beam, which is very narrow, and it is convenient to use a diaphragm with a hole in the middle to trap such unwanted electrons and let the rest through. Since many of them have lost speed in acquiring a deflection, they would blur the picture if included. Thus parts of the image which scatter strongly, like those which absorb, appear dark. The electron microscope has some advantage here over the optical, since slight differences in density affect the scattering power enough to reveal themselves, and it is not usually necessary to stain organic specimens.

This need for thin specimens is the most serious restriction of the present form of the electron microscope. In many cases, e.g. the study of smoke particles or of bacteria, it can be met by using a thin film of collodion or similar material supported on a disc with a small hole or on a very fine wire gauze. Such films are surprisingly strong, stand up well to bombardment by the electrons, and do not confuse the picture by showing a structure of their own. The actual specimens can often be conveniently mounted by suspending them in a drop of water on the collodion and letting the water evaporate.

For some organic objects this method fails, as the object is too thick by itself even without the collodion. Some improvement can be made by using faster, and so more penetrating, electrons. The R.C.A. are developing an instrument using 300,000 volt electrons. With this, Zworykin, Hillier, and Vance have been able to get a satisfactory picture of a section one or two thousandths of a millimetre thick of the body-wall of a cockroach. Theoretically the increased energy gives better resolving power also, but in practice it does not seem to have made any appreciable difference.

While it is possible to make metal films thin enough to give pictures even with 45,000 volts, for much of the work for which the electron microscope would be most useful in metallurgy it is necessary to use massive specimens. To get round this difficulty a number of ingenious devices have been used to prepare thin casts reproducing the surface of the metal, which can then be examined by transmission. In one method silver is evaporated on to the metal surface to be studied, and stripped off mechanically. Then collodion is flowed on to the silver, which is dissolved in acid, leaving the thin collodion film behind. This double process is found by Zworykin to give better results than applying the collodion directly to the original metal.

REFLECTION MICROSCOPES

Obviously devices such as these are subterfuges which are inconvenient and must tend to smudge out the finer details of the structure examined. Many attempts have been made to view objects by reflected electrons, but so far without very much success. If the object is viewed with its surface normal to the direction of sight, as in an ordinary microscope, the electrons, which must come from the sides, have to bend through a right-angle or more, and become so varied in energy that it is impossible to get an image. If, on the other hand, the object is both viewed and illuminated at glancing incidence, the electrons from the part in which one is interested get confused with those from parts before and behind, and in addition the view is very much foreshortened.

A very interesting attempt has been made by Ardenne to view solid objects by scanning,

something in the way that a television image is reproduced. To make the scanning fine enough, the electron microscope is in essence reversed, and a greatly *diminished* image of a small source of electrons is focused on the object. The electrons scattered from a very small region are then caught and recorded either as a spot of light of proportional intensity, or in some other way. By electric means the diminished image is traversed across the object, while the spot of light is moved in synchronism over a photographic film. The blackening of the line on the film will reproduce the variations in electron scattering by the regions of the object on which the electrons have fallen. When the electron beam has crossed the object once it is deflected slightly down and made to cross it again, thus covering the whole object as a page is covered with writing. All the time the spot of light records the scattered electrons on the corresponding part of the photographic film, which thus reproduces the scattering powers of the object with any convenient magnification. The resolving power depends on the ability of the reversed microscope to make a very fine scanning beam. So far this has been only moderately successful, but it clearly has possibilities.

PHOTOGRAPHIC STUDIES

Since the photographic action of fast electrons is the means used to record the image in an electron microscope, it is highly appropriate that the microscope has been used to study the action of the electrons on individual grains. It was known already that long exposure to electrons released metallic silver from silver bromide crystals of the emulsion even without development. The microscope shows that this silver is not uniformly distributed throughout the grain but concentrated in certain preferred patches. Something similar happens when the silver bromide crystals are exposed to very strong light. In this case the small patches of metallic silver probably reveal the latent image centres.

The action of developers can also be shown, and it is found that the silver in the developed grain is in the form of a mass of delicate filaments which may extend beyond the boundaries of the original grain. This is contrary to the view previously held that developed silver was a 'coke-like' substance. The appearance of the filament depends on the developer used; thus metol and amidol give very fine filaments, while those from hydroquinone are coarser. The very minute Lippman crystals of silver bromide, too small to be seen in an optical microscope, have also been studied. Each of these grows on development into a filament much larger than the original crystals.

BACTERIA

It is rather surprising, and fortunate, that bacteria stand up as well to the conditions in the electron microscope as they do. One would have been afraid that bubbles of gas would form in specimens exposed to a high vacuum and burst open the structure and, even if they escaped this, that the bombardment by the electrons would destroy the structure before it could be observed. In fact, they show up well and give good pictures without staining. Burton says that it is still uncertain if they are killed by the exposure. It is still too early for many results to have come out in this field of work, but a good beginning has been made. For example, the mosaic virus, which is responsible for a disease of the tobacco-plant, has been examined though it is quite impossible to see it in the ordinary microscope. This particular virus has been the subject of a brilliant series of researches by Dr Bernal using X-rays, and it is satisfactory that the size shown in the electron microscope confirms that deduced indirectly from the earlier work. This application of the electron microscope is the most exciting of all in the hopes that it holds out of providing a tool of the highest importance in medical research.

SMOKE AND DUST PARTICLES

A number of studies have been made of the structure of smokes. Smoke is a collection of solid particles, many of which are very small, three-quarters of them being invisible to the ordinary microscope. Figure 10 shows the curious shape of the particles in a smoke of zinc oxide formed by burning zinc in air. On the other hand, the particles in carbon black are rounded, and aggregate together in chains; those of aluminium oxide smoke are spheres and those of magnesium oxide mostly cubical, while iron oxide forms little prisms (figure 16).

Besides these artificial smokes, natural dust affords an important field for study, because of its importance in certain diseases such as miners' silicosis.

THE ULTIMATE LIMITS OF VISIBILITY

One is naturally tempted to ask whether there is any hope of seeing individual molecules or even atoms in the electron microscope. Here a good deal depends on what is meant. In a certain sense each crystal of many substances, such as quartz, can be considered as a single molecule, if free from cracks and flaws. If one excludes these, which, of course, are easily visible, the next largest molecules are those either of very complicated organic substances such as some of the proteins, or of the polymerized substances now coming into such extensive use as plastics. From studies with the ultra-centrifuge it appears that some of the more complicated proteins have perhaps twenty thousand atoms in the molecule. If such molecules were solid cubical lumps they would have a side only 20 to 30 atom-diameters long, which would be near the limit for the present instruments. It is, however, much more likely that they have a more open structure so that their outside dimensions would be large enough to be visible. The difficulty is likely to lie in distinguishing them from the material which surrounds them or on which they rest, but in view of the success with microbes it may not prove insuperable.

In the case of the polymers we have relatively simple basic molecules which hook on to one another to form chains and aggregates of almost indefinite extent, as in a crystal, and it may not be an easy matter, or indeed have much meaning, to say where one compound molecule ends and the next begins. Nevertheless the study of these aggregated molecules by the electron microscope promises well. Figure 13, for example, shows the curious growth, like a tangled creeper, of one of these substances, the minute threads probably indicating an aggregation in the form of long chains.

Finally, individual atoms: to see an atom as a speck requires theoretically only sufficient illumination and sufficient contrast. Since a loose atom would move about with a high speed owing to thermal agitation, the atom must be anchored to something, which itself must be made of atoms. The best chance is presumably to have a heavy atom, e.g. of gold, on a support made of light atoms, e.g. collodion. The questions now are: can the atom be illuminated strongly enough to scatter a detectable amount of radiation (light or electronic), and if so, will this not be swamped by that scattered by the support? High resolving power helps, because electrons scattered by the part of the support outside the unresolved range will be focused on other parts of the photographic plate and cause no confusion. The less the region unresolved and so indistinguishable from the atom, the more chance there is that the electrons scattered by the atom itself are a sufficient proportion of the whole number in the region to make this part appear appreciably darker than where there is no heavy atom. Assume a film of celluloid about 100 carbon atoms thick, which is feasible; then if the resolving power were such as to isolate a square 5 atoms each way there would be 2,500 carbon (or oxygen) atoms whose scattering would mix with that of the gold. But the gold weighs some sixteen times as much as a carbon atom, and the scattering is roughly as the weight, so the gold would cause about 1 part in 150 extra scattering. This is a little too small to detect, and we have assumed a better resolving power than is feasible at present, but the experiment looks the kind of thing that may well be successful in the next ten years. To see the component parts of an atom is quite another matter. Here one is up against the fundamental difficulty that electrons, fast enough to have the necessary resolving power, will knock the atom about so much that what one would see would depend as much on the accidents of the collisions as on the original character of the atom. This theoretical limitation, however, does not prevent the electron microscope from being the most promising aid to research in more than one branch of science that has been discovered in the last few years.

Nicolaus Copernicus, 1473–1543

H. DINGLE

Exactly four hundred years ago, the Polish astronomer Nicolaus Copernicus received on his death-bed the first copy of his book *de Revolutionibus Orbium Coelestium*. In the present article, Professor Dingle traces the course of early cosmological theory, and shows that though the progress of Copernicus's conception was slow, his book marked the turning-point of European thought into the scientific channel.

In the history of European thought a few dates stand out as points almost of discontinuity, certainly of abrupt change, and of these 24th May, 1543, is one of the most prominent. On that date, Nicolaus Copernicus received, as he lay dying, the first printed copy of his book, *de Revolutionibus Orbium Coelestium*, which was destined to provide a new basis for astronomy and for the general philosophical outlook by which man's reaction to the world of experience is ultimately determined.

Copernicus was a Pole by birth and probably—though German writers, since his greatness has been recognized, have claimed otherwise—by descent. He was born on 19th February, 1473, at Toruń (Thorn) on the Vistula, where he went to school and whence he proceeded to the University of Cracow, then one of the most famous centres of European culture. Probably through the influence of his maternal uncle, Lucas Watzelrode (under whose care he had passed at the age of 10, on the death of his father), he decided to enter the service of the Church. Watzelrode was a man of considerable strength of character, who had become Bishop of Ermeland during Copernicus's youth and who sought to obtain for his nephew a canonry at the Cathedral of Frauenburg. His first attempt failed, and accordingly Copernicus, on leaving Cracow, proceeded to Bologna to continue his studies in preparation for a more successful attempt to be made later. He remained at Bologna for four years, and although the canonry was obtained during this period, he followed up his sojourn there by further study at Padua, Rome, and Ferrara, returning ultimately to Ermeland in 1506 after some ten years of almost continuous study in Italy.

There can be little doubt that the foundations of his new astronomical ideas were laid during this period, though his studies were not primarily in astronomy. The duties of a canon were manifold, and Copernicus studied law and medicine chiefly, though he evidently gave much thought to astronomical matters, and taught mathematics during his year's residence in Rome. The Professor of Astronomy at Bologna was Novara, a man of original ideas, and we are told that Copernicus worked with him 'not so much a pupil as a helper and witness of the observations.' Copernicus also studied Greek, and in later years published translations into that language of Latin verse. At some time during his career he became proficient in painting, but no specimen of his work survives. He was thus a man of wide interests and attainments, but it is clear that, from an early time, Urania, the Muse of Astronomy, had marked him for her own, and to her he remained faithful to the end of his life.

It was a time of considerable political upheaval, and in the wars between the Poles, the Prussians, and the Teutonic Knights, Ermeland became the centre of much disturbance. Copernicus, in addition to his clerical and medical duties (he was continually called upon to minister to the bodily health of successive bishops and the poor of the diocese), found himself charged with the military defence of his district, which he undertook and prosecuted with some distinction. At the subsequent peace conference he was entrusted with the care of its interests, and when difficulties arose through debasement of the coinage, he made an analysis of the principles of currency, on the basis of which new legislation was established which remedied the evil.

During all this time, however, his new astronomical system was his chief and abiding interest. He tells us in the preface to *de Revolutionibus* that he had worked at it for some thirty years, and the Polish scholar Birkenmajer has traced out, from notes on scraps of paper, margins of books, and even on walls, as well as from the successive amendments of the MS. of *de Revolutionibus*, the growth and gradual modification of his ideas.

NICOLAVS COPERNICVS TORINEVS BORVSSVS MATHEMAT
NAT ANNO 1473 OB. 1543.
Non docet instabiles Copernicus aetheris orbes,
Sed terræ instabiles arguit ille vices

FIGURE 1 – (*top*), *Copernicus's house at Toruń (Thorn) during Napoleon's visit in* 1807.

(The above and the other illustrations throughout the article are by courtesy of the Polish Ministry of Information.)

FIGURE 2 – (*centre, left*), *Copernicus's handwriting.*

FIGURE 3 – (*right*), *Copernicus—a portrait from the Zamoyski collection in the National Library at Warsaw.*

FIGURE 4 – *Copernicus monument, by Thorvaldsen, in Warsaw. The inscription, which means 'Nicolaus Copernicus: His Fellow-countrymen,' has been altered since the German occupation to 'Nicolaus Copernicus: The German Nation.'*

FIGURE 5 – *Copernicus on the tower of Frauenburg.* (From the painting by J. Matejko.)

X

Occasionally he made observations of his own, but he was primarily a thinker, not an observer, and was always ready to accept with respect—perhaps too much respect—the observations of earlier astronomers. He was of a retiring disposition, and despite the promptings of his friends and admirers he hesitated long before publishing his great work. He consented only towards the end of his life, after his young and enthusiastic pupil, Rheticus, who had remained with him for two years studying his manuscript, had, with his permission, published a preliminary account of the work. He had, however, long previously circulated in manuscript form a *Commentariolus* containing a short résumé of his ideas, which were thus well known among astronomers.

To understand Copernicus's work we must know something of the prevailing astronomical and philosophical ideas of the time. These ideas had their source in Aristotle, in whose system of the universe the earth occupied the central, stationary position, while the heavenly bodies were attached to material spheres which revolved ceaselessly with uniform motion round it. The motion of any particular body might be the resultant of the motions of several spheres, for they could communicate their motions to one another. The fixed stars were all attached to the outermost sphere, and their motions, being observed to be simple and uniform, needed no interference from other spheres. The planets, however, including the sun and moon, appeared to move irregularly, and their paths had therefore to be represented by combinations of uniform circular motions. In Aristotle's day, when observations were not very exact, this could be done well enough with fifty-five spheres.

This geometrical system, however, was supplemented by certain physical—or, as we should say, metaphysical—ideas. The material below the lunar sphere, consisting of the four 'elements' earth, water, air, and fire, was changeable and corrupt. It tended to move in straight lines, either towards the centre of the universe by gravity, as with earth and water, or away therefrom by levity, as with air and fire. Such motion could not be eternal, for it had to end when the centre or the outermost sphere was reached, the universe of Aristotle being essentially finite. Celestial matter, however, of which the spheres and the heavenly bodies were composed, was of a more perfect kind, not subject to change and decay, and partaking only of the perfect, eternal, circular movement. In the years which followed, these physical principles were accepted as necessary conditions to which all theories of the structure of the universe must conform, but the steady accumulation of observations made it necessary to modify the system of spheres which Aristotle had found adequate.

By the time of Ptolemy, in the second century A.D., a very different architecture of the universe had become established. Except for the sphere of the fixed stars at the outer boundary of the universe, the perfect material spheres had fallen into neglect and their places had been taken by imaginary circles. Each planet moved on a circle whose centre moved on another circle, and so on, until finally a circle was reached whose centre was stationary with respect to the earth, though not necessarily in it. This ultimate circle was called a *deferent* and the others *epicycles*, and the problem was to conceive a system of such circles which would produce the observed movements of the planets. This was a geometrical problem, and it engaged the best minds of the ancient world. The results of their labours were collected by Ptolemy in his famous *Syntaxis*, or *Almagest*, which embodied the main principles of the astronomy of the next 1,400 years.

As, in the succeeding centuries, observations became more numerous and more exact, modifications of detail were made to adapt the system to the demands of fact—to 'save the phenomena,' as the phrase went. Another problem which developed increasing urgency was that of reconciling the Ptolemaic circles with the Aristotelian spheres, for the authority of Aristotle during the Middle Ages acquired almost the status of divine sanction. Ptolemy had ignored the spheres, but, on the other hand, he had not attached too much weight to the circles. He regarded them as merely a geometrical device, without 'reality,' and he would probably have accepted the spheres as real, though not helpful in saving the phenomena. Subsequent thinkers, however, could not contemplate without uneasiness a philosophy in which the real was useless and the useful imaginary. On one thing all were agreed, namely the sovereignty of the Aristotelian physics—the distinction between the incorruptible heavens and the corruptible earth, and the necessity that all celestial movements should be compounded of uniform circular motions. Despite ingenious efforts, the divorce between reality and practicability remained a thorny problem, and, moreover, as observations accumulated it became increasingly difficult to save the phenomena with any

reasonably simple combination of circles. Such was the state of affairs to which the young Copernicus turned his attention, with a mind awakened to new possibilities by the general spirit of the Renaissance and the particular influence of Novara.

Copernicus accepted the Aristotelian metaphysics with absolute fidelity. He adopted also the traditional eccentrics, deferents, and epicycles as proper geometrical means for representing the phenomena. Furthermore, he accepted the outermost sphere of the fixed stars at a finite distance from the earth. Where he differed from Ptolemy and the general practice of his time, however, was in his rejection of certain devices which, in his view, kept the letter of the Aristotelian rules at the expense of their spirit, and which accordingly made the mechanism of the heavens much more complicated than he considered to be consistent with their dignity. In particular, Ptolemy had regarded a body as moving 'uniformly' in a circle if its angular velocity about *any* internal point was uniform, whether or not that point was the centre of the circle. Copernicus was not satisfied with this, and looked for some way of avoiding it.

He found it in the abandonment of the idea that the earth was stationary. If, instead, the sun were supposed at rest and the earth given certain movements to account for some of the apparent movements of the stars and planets, then not only could strictly uniform motion be preserved, but also the phenomena could be represented by a very much simpler combination of circles. Moreover, the circles would then all move in the same direction instead of some in one direction and some in the other, the general principle of uniformity thus being obeyed in still another particular. By this one change—the change of standard of rest in the universe—Copernicus was able to reduce the number of celestial circles from over eighty to thirty-four. The movements given to the earth were, first, a daily rotation on an axis, to account for the rising and setting of the heavenly bodies; second, an annual revolution round the sun, to account for the apparent movement of the sun along the ecliptic and the retrograde movements of the planets; and third, a conical movement of its axis, to account for the precession of the equinoxes and certain illusory effects which, with others of his time, he believed to be real.

The immediate objection to this change was not aimed, as is commonly believed, at its impiety, but at its absurdity. If the earth rotated, it was said, clouds and bodies thrown into the air would be left behind and fall far to the west, and the great speed of its motion would cause it to fly to pieces. Copernicus could only partly answer these arguments, for the foundations of dynamics still awaited the labours of Galileo. To the objection that the earth's revolution round the sun would require an apparent 'parallactic' movement of the stars, Copernicus replied that such a motion must indeed exist, but owing to the smallness of the earth's orbit compared with the distance of the stars, it was unobservable. This, of course, was the true explanation, but the movement remained undetected for 300 years, though in the meantime other evidence of the earth's revolution had come to light. On the whole, however, the chief evidence for the Copernican system at the time of its origin was the great simplicity it introduced into the description of the heavenly motions; there was little or nothing of a decisive physical character that could be advanced in its favour.

For this reason, the problem which agitated the immediate successors of Copernicus—namely, was the Copernican universe real or only the simplest geometrical means of saving the phenomena?—was by no means an easy one. What Copernicus himself thought on the matter is uncertain, though he doubtless regarded his system as the best means of saving the phenomena. Before publishing his book he wrote a letter, which has been lost, to his friend, Andreas Osiander, which evidently bore on the subject, for Osiander in his reply advised Copernicus to insert a preface stating that hypotheses such as that to be proposed were not articles of faith but bases of calculation, and that it did not matter if they were false so long as they represented the phenomena. When the book appeared it contained such a preface, but it was unsigned and later was found to be the work not of Copernicus but of Osiander, who had seen the book through the press.

There is no doubt that Osiander's object was to placate theologians and philosophers, who, he feared, would regard the book as contrary to the sacred Scriptures. We cannot, however, assume that Copernicus shared this fear. The Pope had heard of the system and had accepted dedication of the book to himself, and high dignitaries of the Catholic Church had urged its publication, one of them, the Cardinal Bishop Schönberg, contributing a foreword. It is not likely, therefore, that Copernicus would have feared suppression, and he tells us, in fact, that it was fear of the ridicule

of the unlearned that had delayed publication. Osiander, on the other hand, was a rather obscure Lutheran, and Luther and Melanchthon had spoken scathingly of the Copernican system, so it is natural that he should wish to defend his adherence to it. There was, in fact, no formal religious objection to the work until long after Copernicus's death, when other questions had arisen to complicate the matter. It was not until 1616, seventy-three years after publication, that *de Revolutionibus* was placed on the *Index*.

In the astronomical world, however, the progress of the Copernican conception, though slow at first, was continuous. It was essential to the work of Kepler, who discovered the elliptical form of the planetary orbits, and to the subsequent work of Newton, which everyone knows. In 1943 we can see that, beyond all question, the book published in 1543 marked the turning-point of European thought into the scientific channel.

Correspondence

(*Continued from page* 124)

THE PLACE OF SCIENTISTS IN THE COMMUNITY (*continued*)

maintain even their present standards of living, scientific and technological research will be needed on a greatly extended scale during and after the period of reconstruction. By such means, and by such means only, can we hope to keep our place as one of the leading nations in the modern world, and since there is very generally some time-lag in the applications of research, the importance of an immediate preparation for the period of reconstruction is urgent.

While, however, the importance of scientific research and of the applications of science in securing industrial prosperity cannot be over-emphasized, there are many responsible scientists who view with some concern the exaggerated claims, which are frequently made by some who profess to speak for science, that all would be well if only a larger proportion of the national income were expended on scientific research and if men of science were given a position of special authority in the affairs of the State. Such claims, we believe, can only foster illusions and be the cause of future disappointment.

The claim sometimes made that the scientist, as scientist, should be given a position of exceptional authority in deciding the policies of governments is one which a democratic community cannot and should not accept. By searching out the facts and by suggesting remedies based on the facts, the man of science can give very valuable assistance in solving many of the problems which face society, and his help should be sought much more frequently and fully than has been the case in the past. Social problems, however, involve not only material but also moral and spiritual values, and are too complex to be solved solely by the methods of science or by any one type of mind. It is the duty not of the scientist, as scientist, but of the community of which he is a member, to weigh the different factors and to make a decision. No despotism could be worse than that of a scientific and soulless technocracy.

[*In view of the controversies associated with the subject of this letter, it was felt that a statement of another point of view was advisable, and Professor J. B. S. Haldane was invited to comment on the letter.* ED.]

From J. B. S. Haldane, M.A., F.R.S.

It is unfortunate that the signatories of the letter on 'The Place of Scientists in the Community' do not state who holds the views which they summarize in the second paragraph, and then attack. I have never met such a person, but am prepared to believe that such exist. Nevertheless I believe that our society (under whatever economic system) would be more efficiently run if a substantial fraction of our rulers were scientifically trained.

The present Government includes one professional scientist and a large number of lawyers. Do the signatories honestly believe that scientists are more 'soulless' than lawyers? Even if they do so, is it not possible that we should be better off if, during the last twenty years, one Chancellor of the Exchequer had been a professional statistician, one Minister of Agriculture a biologist, and one Secretary of State for Air a physicist? The signatories all combine administrative and scientific ability. They have all sacrificed time from research to work in organizations. Men with just such abilities could, and I believe should, play a larger part in government.

Scientists should not confine themselves to giving help on technical matters when asked. Their special knowledge enables them to detect evils and to suggest remedies which are not obvious to others. In so far as they can do this it is not merely their right, but their duty as democrats, to ask their fellow-citizens to put them in positions 'of special authority in the affairs of the State,' for example in Parliament. Members of other callings have similar rights and duties. When, if ever, there are as many scientists as lawyers or company directors in the Cabinet, it will be time to talk of the dangers of a 'scientific technocracy.' Till then, scientists need not, and should not, avoid political activity.

Forests of the sea

F. E. FRITSCH

The variety and profusion of the marine flora are very inadequately appreciated by the average man and woman, to whom, as often as not, seaweed is just seaweed. Professor Fritsch's article indicates that the forests of the sea are comparable in interest with those of the land, and contain a multiplicity of striking forms—some of giant dimensions.

The brown seaweeds that densely clothe the rocks between tide-levels (figure 1) on the British and other northern shores mainly comprise the bladder and serrated wracks (*Fucus vesiculosus* and *F. serratus*), often accompanied by the slightly larger *Ascophyllum*, with strap-shaped fronds dilated by occasional air-bladders. The daily exposure to drying and temperature extremes is probably responsible for the relatively small size of these seaweeds. *Fucus* plants rarely exceed a yard in length, and are small compared with the oarweeds (*Laminaria*) that occupy the permanently submerged shore-line, so that they are uncovered only at low water of spring tides (figure 2). Members of the oarweed group, or Laminariales, are important elements of the marine flora in colder seas all the world over, and they are remarkable for their large dimensions, as well as for their customary growth in dense communities, which may aptly be compared with the forests of the land.

The flexible stalk or stipe of the oarweeds bears a simple (figure 3) or divided blade. The plants often reach a length of 4 or 5 yards, while the stalks of older individuals may be an inch across and show growth-rings like the trunk of a tree. Certain Norwegian and American Laminarias are appreciably bigger, while some of the Pacific Laminariales are among the largest plants known. Growing as they do in extensive beds in several fathoms of water, they commonly constitute natural breakwaters, reducing the erosive action of the sea on the adjacent coast.

Most oarweeds are perennials, the stalk becoming longer and thicker year by year, while each spring a new blade arises from a formative region at the top of the stalk (figure 4) and replaces that of the previous season. The new blade is always undivided and remains so in some oarweeds (figure 3), but in others (e.g. *Laminaria digitata*) it develops successive splits (figure 4), which, extending to the margin, divide the greater part of the blade into narrow segments, the whole ultimately resembling a huge many-fingered hand. In all Laminariales the young plants have short stalks and simple blades, and the various forms exhibited by the adult seaweeds are mostly due to the formation of similar splits, which may also extend into the stipe, so that the individual blades frequently have short stalks of their own.

Among the many striking forms found in other oceans, one of the most noteworthy is the bull-kelp (*Nereocystis*, figure 5), with a stipe that may be 40 yards long, while the numerous blades are supported near the surface by the large float which alone is visible from the shore (figure 6). This annual, which appears about February and lasts into the following winter, illustrates the rapid growth observable in these giant seaweeds. The similar elk-kelp (*Pelagophycus*), so called because the blades are distributed along two horizontal branch-stalks situated above the float, is restricted to California. Both it and *Nereocystis* often get carried out to sea in rough weather and may be found drifting miles away from the nearest mainland. *Pelagophycus*-drift is so regularly encountered off the Californian coast that the Spaniards took is as a trustworthy token of the proximity of land and adjusted the ship's course as soon as it was sighted.

Along the whole western coast of America there are huge tracts of *Macrocystis* (figure 7), although its chief home is in South Temperate and Antarctic seas. Here flotation is secured by the small air-bladders situated at the bases of the crowded 'leaves' (figure 8). The possession of such floats, as well as the buoyant properties of the water, enables these forms to expose their blades near the surface, where they can obtain the light-energy required for building up their substance from the carbon dioxide absorbed from the water. Certain smaller Laminariales have stronger stalks so that they remain upright even when unsupported. This is so in the sea-palm (figure 9), the dense

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FIGURE 2 – *At low tide luxuriant growths of large oarweeds (especially* Laminaria digitata*) are sometimes exposed, as in the photograph. Another species of oarweed that inhabits deeper water is just visible above the surface of the sea on the left. The photograph was taken on the shores of The Faeroes by Dr F. Boergesen.*

FIGURE 1 – *Attached to the rocks (between tide-levels) on temperate shores one finds a profuse growth of various fucoids. The photograph, taken by Dr F. Boergesen in The Faeroes, shows a dense mass of the bladder-wrack* (Fucus vesiculosus)*, with a little* Ascophyllum *appearing near the base.*

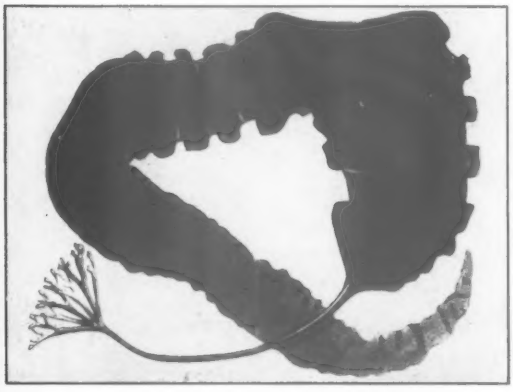
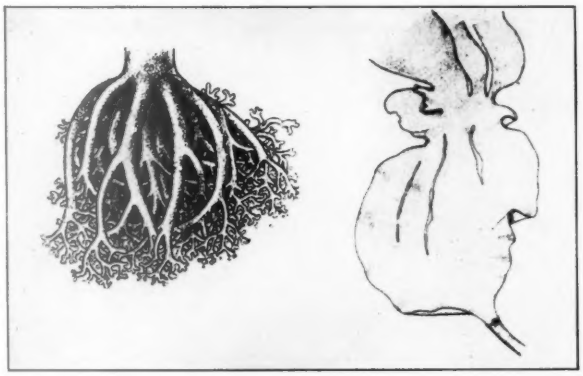


FIGURE 3 – *The photograph (after Harvey) shows a small individual of the simple-bladed oarweed* (Laminaria saccharina) *reduced to about one-sixth. As in all members of the oarweed group, the plant consists of a basal attaching organ, a stalk, and a long leafy blade.*

FIGURE 4 – *By means of their richly branched holdfasts, one of which is represented on the left, the oarweeds gain a firm hold on the rocks. Plants cast up after storms are often intact, with fragments of rock still clinging to the holdfasts. The right-hand figure shows the new season's blade of a digitate oarweed arising beneath the remains of the old: the first splits are visible in the new blade. (After Sauvageau and Setchell.)*



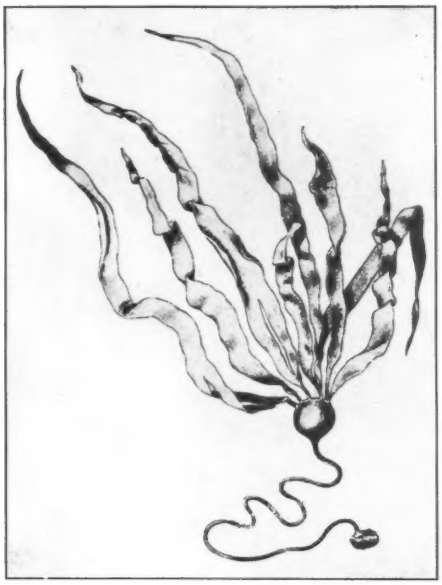


FIGURE 5 – *The bull-kelp* (Nereocystis), *one of the biggest of the sea-weeds, occupies large areas of the sea-bottom off the Pacific coasts of North America; it grows in* 8–10 *fathoms of water. The blades that arise by progressive splitting are held at the surface by the huge float situated at the top of the stalk. This is a relatively young plant (after Postels and Ruprecht); older ones have much thicker stalks and more numerous blades.*

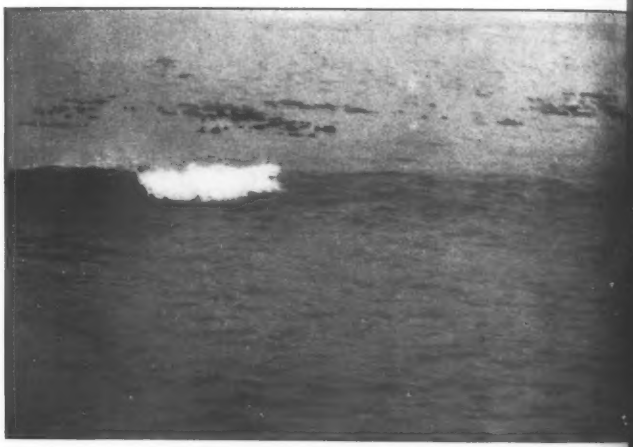
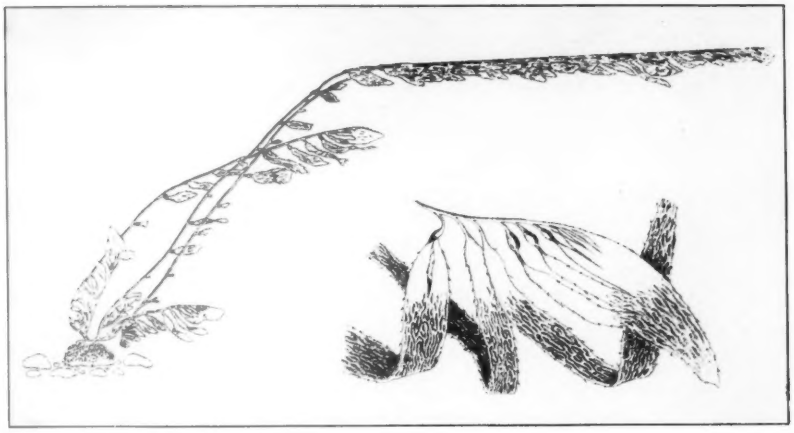


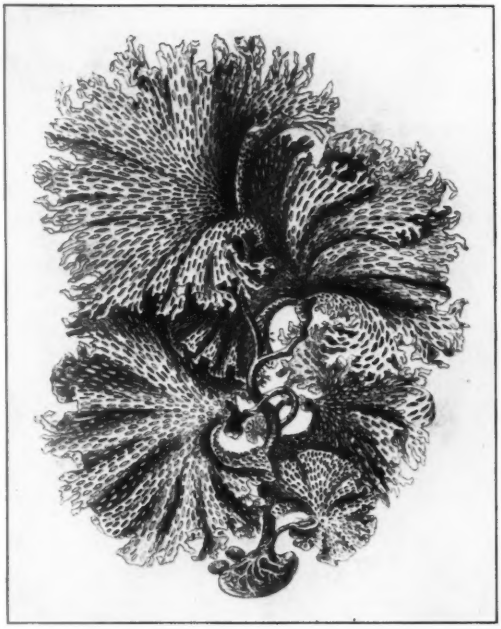
FIGURE 6 – *Seen from th the floats of the numerous cystis plants appear as da jects, bobbing up and dou the play of the waves.*

FIGURE 7 – *The largest of the ext European Laminariales is* Macrocys *which may reach a length of* 200 *ft. fr end to end. It is abundant off many parts the shore of California (where the pho graph was taken), forming extensive b that act as natural breakwaters.*



GURE 8 – *The slender stalks of* acrocystis *rise obliquely to the face of the sea, where they trail for long distances, floating with help of small bladders situated the bases of the numerous serrated nds. Only these floating portions visible in the preceding photo-ph. From the scimitar-shaped of the floating stalk (right-nd figure) the numerous blades split off progressively. (After ttsberg.)*

FIGURE 9 – *The sea-palm* (Postelsia) *is a much smaller form growing gregariously just above low tide level on the coasts of the Pacific (North America). Here the thick sturdy stalk stands erect, and, when uncovered by the sea, the numerous blades hang down alongside it. The plants reach a height of about* 18 *in.*



E 10 – *One of the most remarkable seaweeds of the oarweed the Arctic* Thalassiophyllum, *growing to a height of about a The firm, twisted stipe bears a number of blades, rolled up along like a cornet and perforated by numerous regularly arranged holes. Postels and Ruprecht.)*

FIGURE 11 – *Among the largest of northern seaweeds are the Alarias, in which the rather short stalk puts out each year a number of outgrowths which bear the reproductive organs. Both they and the thick rib which stiffens the long blades are items of human diet in various parts of the world.* (*After Kjellman.*)

FIGURE 12 – *The seaweed* Egregia *forms extensive meadows at and below low tide level on the Pacific coasts of North America. The long drifting and sparsely branched stalks are closely beset with small leafy blades, and also bear occasional floats.*

FIGURE 13 – *This plant of* Egregia (*not inaptly called the feather-boa kelp*) *was about* 6 *yards long. Note the floats which enable the fronds to drift at the surface.*

growths of which are quite unaffected by the buffeting of the Pacific breakers. In the Antarctic Lessonias, the sturdy stipes (up to 3 yards long) may be as thick as a human thigh and, when the numerous blades have decayed, the stipes of cast-up plants look deceptively like logs of wood.

The repeated splitting of the blades that occurs in these diverse forms affords a large surface for light-absorption, and at the same time one that yields readily to the play of the waves. Other Laminariales exhibit a different device, namely the formation in the enlarging blades of numerous holes through which the water can flow. This is so in the Arctic Agarums, where the blade is undivided, as well as in *Thalassiophyllum* (figure 10), which forms small submarine forests in the Bering Sea and off the shores of Alaska.

All Laminariales propagate by motile cells that give rise to a microscopic generation producing the new seaweed. The reproductive cells are formed in crowded receptacles covering large areas of the ordinary blades. In the Alarias, however, they are restricted to special outgrowths formed on the short stalk (figure 11). The vegetative blade grows to great lengths; in the British *Alaria esculenta* it may be more than 6 yards long, while in the Pacific *A. fistulosa* it may reach 25 yards, with a width of 6–7 ft. In *Egregia* (figure 12) the plants consist almost entirely of the flattened stipes which produce innumerable leafy outgrowths (figure 13), while the original blade remains quite small.

Both the intertidal fucoids and the *Laminarias* have long been used as manure, their value in this respect being partly due to their high content of potassium. Before the exploitation of the Stassfurt deposits, the ash or kelp obtained from such seaweeds after burning indeed furnished the chief source of potassium and was extensively used in the preparation of soap and glass. It also afforded iodine, in which *Laminaria* is particularly rich. The kelp industry was widespread in Northern Europe, and in France the rivalry between those collecting the seaweed as manure and those burning it for ash became so violent that its use had to be regulated by statute. More recently, the algin derived from the mucilage of *Laminaria*, *Nereocystis*, etc., has been put to various uses, as for instance in the making of adhesives and of a kind of artificial silk, and there can be no doubt that there will be a wider exploitation of brown seaweeds in the future. Near Puget Sound (U.S.A.) the annual production of *Nereocystis* has been estimated at some 200,000 tons, while the kelp beds on the Californian coast are stated to cover about 400 square miles, producing annually 59,300,000 tons of fresh kelp. The Laminariales do not provide much human food, although Alarias are so utilized in various regions, and the Japanese prepare a diversity of food products from Laminarias.

Research activities in China

As the highest research organization under the Chinese National Government, the Academia Sinica, despite the limitations on its finances, personnel, and equipment, has carried on an extensive programme throughout Free China. It maintains ten institutes: those of Physics, Chemistry, Engineering, Geology, Astronomy, Meteorology, Zoology and Botany, Psychology, History and Philology, and the Social Sciences.

Until July 1937 the first three were situated in Shanghai, while the central office and the other seven institutes were all in Nanking. At present, the central office is temporarily in Chungking; the institutes of Zoology and Botany, Meteorology, History and Philology, and Social Sciences are in two localities in Szechuan; the institutes of Chemistry, Astronomy, and Engineering are in Kunming; and the institutes of Physics, Geology, and Psychology are in Kweilin.

The National Research Council was organized as a part of the Academia Sinica in 1933. Its function is to promote and co-ordinate scientific research in the whole country, the word 'scientific' being used in the wider sense, including the social and historical sciences.

Members of the council consist of the president of the Academia Sinica, the directors of its research institutes, and thirty members elected by professors of national universities. The term of office of the elected members is five years. The council ordinarily meets once a year.

The Academia Sinica was founded in 1928 in Nanking with the late Dr Tsai Yuan-Pei as its president. After his death in March 1940, the National Government appointed Dr Chu Chia-Hua acting president. During the period 1939–41, H. C. Zen and Fu Sze-Nien successively served as secretary-general. The latter resigned in the autumn of 1941 and Dr Yeh Chi-Sun, professor of physics in the National Chinghua University, was appointed to the post.

The electrometric determination of *p*H and some of its applications

H. T. S. BRITTON

The precise measurement and adjustment of hydrogen-ion concentration have had considerable value in many industrial, commercial, and agricultural operations. Their use in the problems of pure inorganic chemistry, while less spectacular, is of equal importance, as Professor Britton indicates by the consideration of some typical examples.

PRINCIPLES

In recent years much attention has been devoted to the importance of hydrogen-ions in chemistry and in many industrial processes. The object of this article is to discuss briefly the significance of *p*H and its measurement and to give an idea of how *p*H determinations have assisted in the solution of some chemical problems.

As water constitutes a system in which the equilibrium $H_2O \rightleftharpoons H^{\cdot} + OH'$ is governed by $K_W = [H^{\cdot}]\,[OH']$, it follows that the concentration of hydrogen-ions, $[H^{\cdot}]$, is related to that of the hydroxyl-ions, $[OH']$, by $[H^{\cdot}] = K_W/[OH']$, which applies to all aqueous solutions. A convenient method of expressing hydrogen-ion concentration is that introduced by Sörensen in terms of *p*H, which is the negative power to the base 10 of the hydrogen-ion concentration, i.e. $[H^{\cdot}] = 10^{-pH}$, or $pH = -\log_{10}[H^{\cdot}]$. For pure water, $[H^{\cdot}] = [OH']$, and therefore $[H^{\cdot}] = \sqrt{K_W}$. At ordinary temperatures $K_W = 10^{-14}$ approx., and therefore $[H^{\cdot}] = 10^{-7}$, whence the *p*H corresponding to true neutrality is *circa* 7. Assuming hydrochloric acid to be completely ionized in a decinormal solution, then its *p*H would be 1, whereas for a decinormal solution of a completely ionized base $[OH'] = 10^{-1}$, whence $[H^{\cdot}] = 10^{-14}/10^{-1}$, and therefore its *p*H would be 13. Similarly the *p*H of a centinormal solution of an ionized acid is 2, whereas that of a centinormal solution of an ionized alkali is 12. Hence acidity and alkalinity can be considered in terms of a *p*H scale ranging from 0 to 14, with *p*H 7 marking the stage when acidity changes over to alkalinity, the criterion of acidity being that $[H^{\cdot}] > [OH']$ and of alkalinity that $[H^{\cdot}] < [OH']$. It should always be borne in mind that the *p*H scale is a logarithmic one, in which any *p*H value refers to a concentration of hydrogen-ions which is one tenth of the concentration indicated by a *p*H value 1 unit smaller.

The direct method of measuring the concentration (or activity) of hydrogen-ions is by means of the hydrogen electrode. Several other methods are available for *p*H determinations, but it must be emphasized that they all depend on the hydrogen electrode, for they have all been standardized by reference to it. These methods are: (i) *electrometric:* the quinhydrone electrode, metal-metal oxide electrodes (of which the most important is the antimony electrode), and the glass electrode; (ii) *colorimetric: without*, and *with*, the aid of standard buffer solutions.

The hydrogen electrode is of limited application as it cannot be used in the presence of many oxidizing agents, neither can it be used in solutions containing cations of metals more noble than hydrogen. Catalytic reduction can be minimized by using coarse platinum black deposits on the electrodes, such that the potentials first set up are those caused by equilibrium with the hydrogen-ions before the subsequent reduction effects have time to appear. This applies to dilute solutions of nitric and chromic acids and to blood. The quinhydrone suffers from these limitations to a much less extent, so much so that it can be used with unsaturated acids and in the presence of cupric ions. Its great drawback is that it cannot be used in alkaline solutions, i.e. with *p*H values greater than 7. The antimony electrode is finding increasing application, particularly in industrial processes and in medical research. Its potentials can easily be calibrated in terms of *p*H values, but as these potentials depend upon the age and nature of the oxide which is formed upon its surface, the electrode requires to be frequently standardized. Substances in solution, such as free acid or alkali or salts of hydroxy acids, tend to impair the antimonious oxide film and therefore to render the antimony electrode as a hydrogen-ion indicator somewhat erratic. Under ordinary conditions its

potential is approximately a linear function of *p*H from 1 to 11, and within smaller *p*H ranges it can be made to indicate readily *p*H values to within ± 0·05 *p*H unit, which accuracy is adequate for many industrial purposes.

Provided a suitable glass be employed, which should preferably be one of sodium calcium silicate (e.g. SiO_2 72 per cent., Na_2O 22 per cent., CaO 6 per cent.), glass electrodes can be prepared the potentials of which bear a definite relationship to those which would be established at a hydrogen electrode immersed in the same solutions up to a *p*H of 9·5. In solutions of higher *p*H values the electrode enters into equilibrium with both hydrogen-ions and sodium-ions, but if the glass electrode has been calibrated in solutions having the same sodium-ion concentrations as the solutions being tested, the electrode can be used up to a *p*H of 13 or even higher. The glass electrode consists of an exceedingly thin glass diaphragm which separates two aqueous solutions, one being a buffer solution of known *p*H and the other the solution undergoing test. Two difficulties, however, arise in using the electrode. The first is caused by the very high resistance of the glass membrane—several megohms—which imparts to the cell combination a very high internal resistance and thus makes the measurement of its E.M.F. a problem of some difficulty. By thoroughly insulating the copper wire lead from the glass electrode to the measuring unit and by employing thermionic valve amplification, the exceedingly small current through the glass cell can be magnified sufficiently to operate the usual measuring instruments such as millivoltmeters (which in turn can be made self-recording, figure 1), electric bells, etc. The second difficulty lies in a slight difference between the surfaces of the membrane. This might have been introduced during the blowing of the membrane or it may be produced by the chemical action of test solutions themselves, especially if they are of high *p*H (11–14) or low *p*H (1–3). This additional potential difference is the so-called *asymmetry E.M.F.* At first a glass electrode has generally a high asymmetry E.M.F., which gradually diminishes with use. Employment of the electrode in solutions of widely different *p*H may cause haphazard variations, but when it is used in solutions of similar *p*H the variations are usually negligible over a period of a day; moreover, the asymmetry E.M.F. remains sensibly constant throughout the complete *p*H range. This makes it possible to convert the E.M.F. of a glass cell, measured with a thermionic valve voltmeter, directly into *p*H values; a buffer solution of known *p*H is used in place of the test solution in the glass cell, and the *p*H scale attached to the voltmeter is adjusted so that the needle indicates that particular *p*H.

All the cells used for the electrometric determination of *p*H values involve the interposition of a saturated solution of potassium chloride between the hydrogen electrode, or its substitute, and the standard electrode, usually either the 'normal' or the 'saturated' calomel electrode. Because of the approximately equal ionic mobilities of the potassium and chloride ions, it is considered that such a solution will eliminate, or else reduce to a negligible amount, the potential difference which otherwise would be set up at the point where the two electrode solutions meet. The use of these liquid junctions renders the applicability of the G. N. Lewis 'activity theory' to this type of cell extremely dubious and uncertain. Hence *p*H values obtained from such cells cannot strictly be considered in terms of hydrogen-ion activities. Occasionally, workers select potentials for the standard electrodes which have been referred to the 'activity' standard hydrogen electrode, and which have been computed from the E.M.F.s of cells *without* liquid junctions. This is inconsistent. Most of the buffer solutions have been standardized with the hydrogen electrode in conjunction with a calomel electrode, the potential of which has been referred to the original arbitrary standard, viz. a hydrogen electrode, supplied with hydrogen at atmospheric pressure, immersed in a solution which, on the basis of the Arrhenius theory, was believed to contain 1 gram-ion of hydrogen-ions per litre. Although serious objections may be raised against the computation of ion concentrations from conductivity measurements, it seems desirable to retain this fundamental standard for the purpose of *p*H determinations if only for the sake of uniformity and consistency. Whatever may be the true meaning of *p*H values, they constitute an invaluable method of stating precisely the intensity of acidity or alkalinity.

Schematically (as a brief reference) the cells used are as shown overleaf ((2), (3), (4)).

Britton and Robinson found λ to increase progressively from + 0·263 volt to 0·302 volt as the *p*H is raised from 1·81 to 11·94. Over small *p*H ranges, e.g. 3 *p*H units, λ is sufficiently constant for the voltmeter used to be converted into a direct *p*H-reading instrument, when once the *p*H scale has been adjusted by testing the antimony electrode in a solution of known *p*H.

(1) *Hydrogen:* $\overset{+}{Hg}$ | $Hg_2Cl_2 \cdot KCl_{(c)}$ | Satd. KCl | Test soln. | $\bar{H}$

$$E.M.F. = E_{Calomel} + 0{\cdot}000198{\cdot}4 \times T \times pH$$

(2) *Quinhydrone:* $\overset{+}{Pt}$ | Test soln. + Quinhydrone | Satd. KCl | $KCl \cdot Hg_2Cl_{2(c)}$ | $\bar{H}$

$$E.M.F. = 0{\cdot}7175 - 0{\cdot}00074 \times t^\circ - 0{\cdot}0001984 \times T \times pH - E_{Calomel}$$
(t° = ° Centigrade; T = ° absolute)

(3) *Antimony:* $\overset{+}{Hg}$ | $Hg_2Cl_2 \cdot KCl_{c}$ | Satd. KCl | Test soln. Sb_2O_3 | $\bar{Sb}$

$$E.M.F. = E_{Calomel} - \lambda + 0{\cdot}0001984 \times T \times pH$$

(4) *Glass* $\overset{+}{\text{Soln. of known } pH\ (pH_K)}$ | Thin glass membrane | $\bar{\text{Test soln. } (pH_T)}$

(i) Hg | Hg_2Cl_2·N·KCl | Satd. KCl | Soln. of known pH_K | Glass | Test soln. *p*H | Satd. KCl | N·KCl·Hg_2Cl_2 |

(ii) Hg | Hg_2Cl_2·0·1N·HCl | Glass | Test soln. | Satd. KCl | N·KCl·Hg_2Cl_2 |

(iii) Ag | AgCl·0·1N·HCl | Glass | Test soln. | Satd. KCl | N·KCl·Hg_2Cl_2 |

(iv) Pt | *Quinhydrone:* 0·1N·HCl | Glass | Test soln. | Satd. KCl | N·KCl·Hg_2Cl_2 |

The actual magnitude of λ is determined by the actual, though exceedingly small, solubility of the Sb_2O_3, present on the surface of the electrode, in the solution undergoing test; and this is influenced by the size, the age, and the treatment of the oxide layer. Frequent standardization of the electrode will therefore be necessary. The polarity of the cell is as shown above, (4), when $pH_T > pH_K$, whence E.M.F. = $0{\cdot}0001984\ T\ (pH_T - pH_K) + E_{Asymmetry}$. Unfortunately the E.M.F. between two solutions cannot be directly measured, and therefore electrical contact with the two solutions is made by means of electrodes having fixed potentials, as shown above, (i), (ii), (iii), (iv). In combination (i) the two calomel electrodes equally oppose one another, whereas in (ii), (iii) and (iv) the left-hand electrodes establish constant potentials both at the terminal metal electrodes and at the left side of the glass membrane. The E.M.F. of a glass cell combination is therefore equal to the E.M.F. given by the foregoing expression *plus* a fixed E.M.F. equal to the difference between the potentials of the two auxiliary terminal electrodes (= E_{Fixed}).

Hence: $E.M.F. = E_{Fixed} + E_{Asymmetry} \pm 0{\cdot}0001984 \times T \times (pH_T - pH_K)$

APPLICATIONS

To illustrate a few of the possibilities of these *p*H electrometric methods in studying chemical reactions, reference will now be made to some work which has been carried out by the author and his research students.

Metallic hydroxides, or more generally basic salts, are each precipitated within narrow *p*H ranges characteristic of the particular hydroxides (cf. Table). The concentration of the metallic

HYDROXIDE PRECIPITATION *p*H FROM DILUTE SOLUTIONS

$Mg^{..}$	*p*H 10·5	..	$Be^{..}$	*p*H 5·7
$Mn^{..}$	8·5–8·8	..	$Fe^{..}$	5·5
$La^{...}$	8·4	..	$Cu^{..}$	5·3
$Ag^{.}$	7·5–8·0	..	$Cr^{...}$	5·3
$Ce^{...}$	7·4	..	$UO_2^{..}$	4·2
$HgCl_2$	7·3	..	$Al^{...}$	4·1
$Pr^{...}$	7·1	..	$Hg_2^{..}$	3
$Nd^{...}$	7·0	..	$Th^{....}$	3·5
$Zn^{..}$	7·0	..	$In^{...}$	3·4
$Sa^{...}$	6·8	..	$Ce^{....}$	2·7
$Co^{..}$	6·8	..	$Hg(NO_3)_2$	2
$Y^{...}$	6·8	..	$Sn^{....}$	2
$CdSO_4$	6·7	..	$Sn^{..}$	2
$Ni^{..}$	6·7	..	$Zr^{....}$	2
$Pb^{..}$	6·0	..	$Fe^{...}$	2

salt solution from which precipitation occurs has a small effect on the *p*H of precipitation. Anions, however, have but little effect, except in the case of bivalent mercury and cadmium. Basic carbonates, chromates, borates, etc., precipitate at the respective metal 'hydroxide *p*H' when the various metal salt solutions are treated with the alkali salts of the corresponding weak acid. To precipitate normal carbonates and chromates of heavy metals the solubility product requirements must be satisfied in the mother-liquor at a *p*H lower than the 'hydroxide *p*H,' or a basic salt will separate.

URE 1 – *Cambridge automatic* p*H recorder, fitted to tanks used in the manufacture of fine micals. The electrodes of the 'dip-type system' (figure 2) are seen on the left.*

(By courtesy of the Cambridge Instrument Company Limited.)

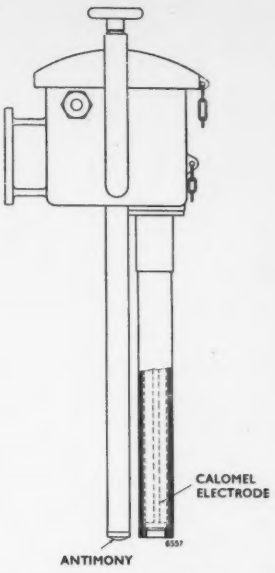
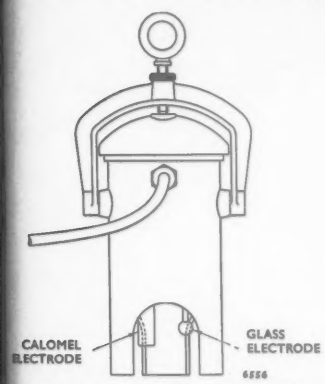


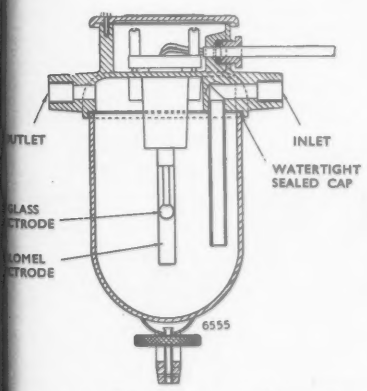
FIGURE 2 – *Cambridge dip-type electrode system specially designed for industrial work. One limb consists of an insulated tube carrying a plug of antimony; the other carries a calomel electrode.*

(By courtesy of the Cambridge Instrument Company Limited.)



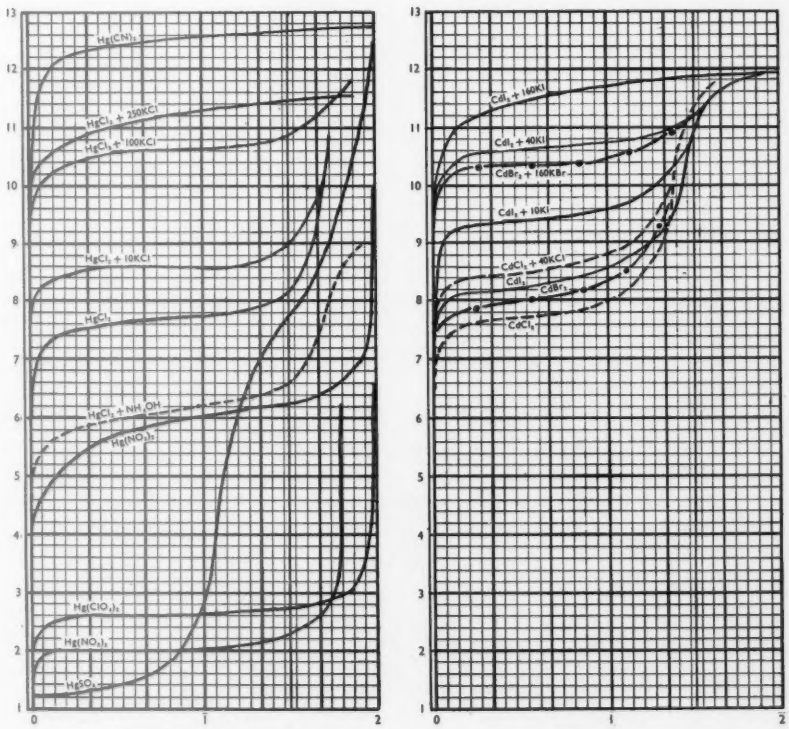
URE 3 – *Cambridge submersible elec- system. The electrodes are contained in lindrical body of rubberized metal cut so as to allow free access of the liquid. electrodes may be either glass-calomel or mony-calomel.*

courtesy of the Cambridge Instrument Company Limited.)



URE 4 – *Cambridge continuous-flow ode system, which is fitted directly into pipe-line. The electrodes may be either and calomel or antimony and calomel.*

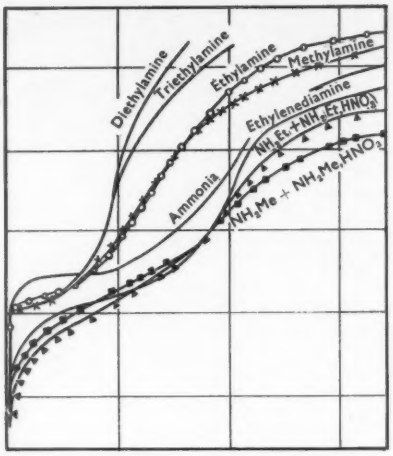
courtesy of the Cambridge Instrument Company Limited.)



Britton and Wilson, *J. Chem. Soc.*, 1932, 2550; 1933, 601.

Moeller and Rhymer, *J. Phys. Chem.*, 1942, **46**, 477.

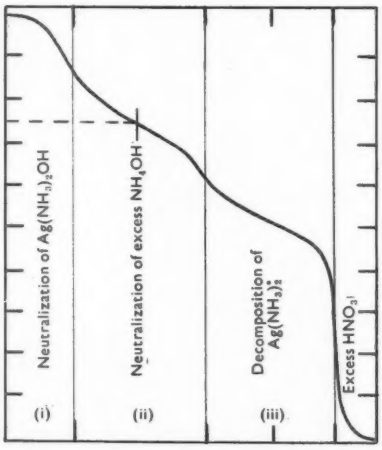
FIGURE 5 – p*H curves illustrating precipitation from mercuric and cadmium salt solutions.*



Britton and Wilson, *J. Chem. Soc.*, 1933, 1050; Britton and Williams, *ibid.*, 1936, 96.

FIGURE 6 – p*H changes during addition of* NH_4OH *and substituted ammonias to silver nitrate solution, which show the formation of the complex salts:*

$Ag(NH_3)_2NO_3$, $Ag(CH_3NH_2)_2NO_3$; $Ag(C_2H_5NH_2)_2NO_3$; $AgC_2H_4(NH_2)_2NO_3$.



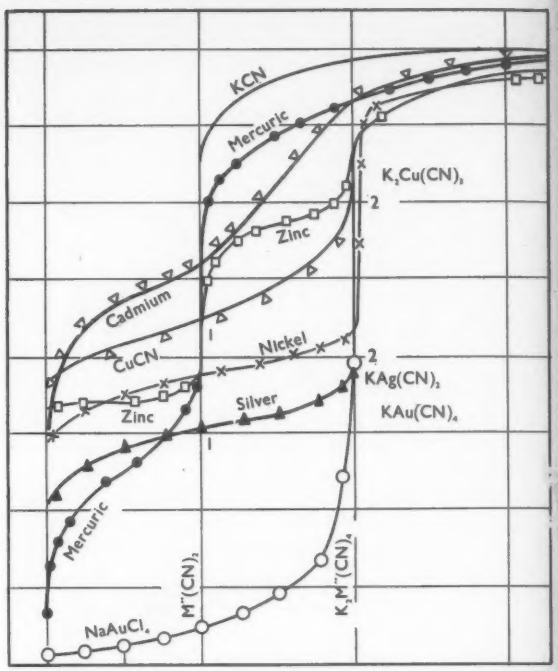
Britton and Wilson, *J. Chem. Soc.*, 1933, 1050; Britton and Williams, *ibid.*, 1935, 796.

FIGURE 7 – p*H neutralization curve of an ammoniacal solution of silver oxide showing the three separate stages represented by the equations:*

(*i*) $Ag(NH_3)_2OH + HNO_3 \rightarrow Ag(NH_3)_2NO_3$.

(*ii*) $NH_4OH + HNO_3 \rightarrow NH_4NO_3$.

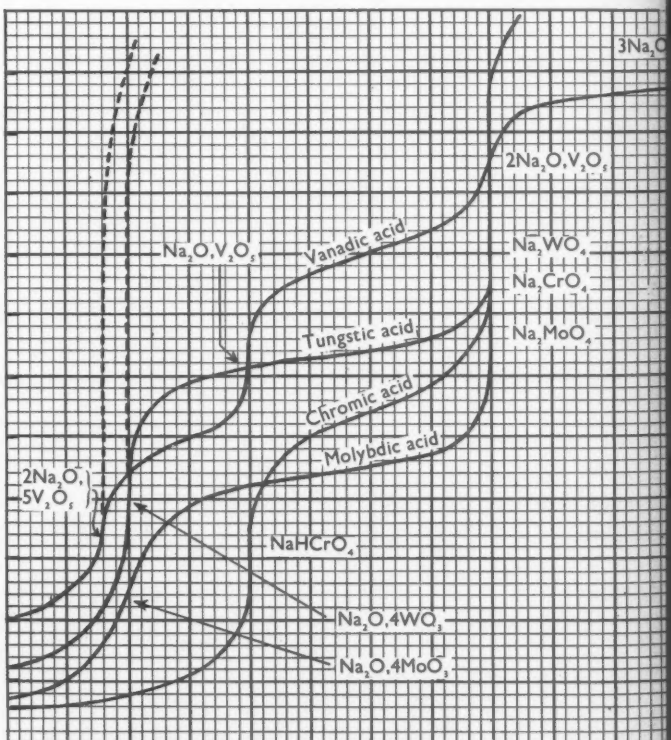
(*iii*) $Ag(NH_3)_2NO_3 + 2HNO_3 \rightarrow AgNO_3 + 2NH_4NO_3$.



KCN, mols.

Britton and Dodd, *J. Chem. Soc.*, 1932, 1940; *ibid.*, 1935, 100.

FIGURE 8 – p*H curves showing the formation of complex cyanides. (The curve marked* KCN *gives the* p*H values which would have been set up if only the cyanides of the metals had been formed.)*



NaOH, equivs.

Britton, *J. Chem. Soc.*, 1924, **125**, 1572; Britton and Welford, *ibid.*, 1940, 764; and Bevan, unpublished.

FIGURE 9 (*right*) – p*H neutralization curves showing* (1) *that chromic acid is a normal dibasic acid;* (2) *the abnormal features of molybdic, tungstic, and vanadic acids.*

EXAMPLE

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That metal hydroxides precipitate at characteristic *p*H values makes their separation possible either by adding alkali and controlling the *p*H, found by direct measurement, or by including in the solution a buffer system that will prevent the attainment of a particular 'hydroxide *p*H' on adding alkali and so prevent the precipitation of that hydroxide.

Figure 5 gives some *p*H precipitation curves of mercuric oxide and cadmium hydroxide—the horizontal sections before the inflexion representing the *p*H during the course of precipitation. Mercuric oxide is a very weak base and the sulphate, nitrate, and perchlorate are strongly hydrolysed and ionized. The consequence is that mercuric oxide is precipitated below *p*H 3. Mercuric nitrite, acetate, chloride, bromide, and cyanide are, however, almost unhydrolysed and un-ionized in solution. This is reflected in the *p*H at which alkali causes precipitation, e.g. from the chloride between *p*H 7 and 8, and only in extremely alkaline solutions from the cyanide. Incidentally, these salts form complex salts of the type K_2HgR_4 when the corresponding potassium salts are present in the solution. The curves marked 10, 100, and 250 KCl show the effect which these increasing amounts have on the *p*H of precipitation when added to mercuric chloride in the ratios indicated. By employing large amounts precipitation may be entirely prevented. This explains why mercuric oxide dissolves in potassium chloride, bromide, or iodide solutions with the liberation of an equivalent amount of alkali, thus:

$$H_2O + HgO + 4KI \rightarrow K_2HgI_4 + 2KOH$$

Figure 5 (*right*) shows that similar effects are produced with cadmium chloride, bromide, and iodide.

The broken line in figure 5 (*left*) refers to the addition of ammonia to mercuric chloride. Precipitation occurred at about *p*H 6, which is lower than when alkali was added. Both precipitates were mainly $3HgO,HgCl_2$, but the ammonia precipitate contained, in addition, co-ordinated NH_3, thus: $3HgO,HgCl_2,2NH_3$. These white ammoniated precipitates have the general formula $xHgO,HgCl_2,2NH_3$, and as such are basic salts which are related to 'fusible white precipitate,' $HgCl_2,2NH_3$, which is precipitated when ammonia is added to a solution of mercuric chloride and a large amount of ammonium chloride—the effect of the latter being to repress the ionization of the precipitant and at the same time to form $(NH_4)_2HgCl_4$, so that only the insoluble co-ordinated compound is precipitated.

Figure 6 illustrates the formation of co-ordinated silver salts when ammonia and substituted ammonias are progressively added to silver nitrate; in some cases, the nitrate of the free base was included in the solution to repress the ionization of the added base. Many curves, in being inflected when two equivalents of base, (B), were added, show that the salts $Ag(B_2)NO_3$ must have been formed. These salts are those of strong bases, $AgB_2OH \rightleftharpoons AgB_2^{\cdot} + OH'$, and this can be shown by titration with nitric acid of solutions of the organic bases in which silver oxide has been dissolved. The *p*H curve of such a titration is given in figure 7, the first section of which corresponds to the neutralization of $Ag(NH_3)_2OH$ and shows that the base is comparable in strength with that of alkali.

Complex cyanide formation is indicated by several of the curves in figure 8, which refer to the addition of potassium cyanide to metal salt solutions, except the one marked CuCN, which refers to a suspension of cuprous cyanide. The final inflexions show that $KAu(CN)_4$, $KAg(CN)_2$, $K_2Cu(CN)_3$, $K_2Ni(CN)_4$, and $K_2Zn(CN)_4$ are formed.

The neutralization curves of the acids shown in figure 9 show that (1) chromic acid is a normal dibasic acid, the first inflexion marking the formation of $NaHCrO_4$ (not $Na_2Cr_2O_7$), and the second of Na_2CrO_4; (2) tungstic and molybdic acids are abnormal, in that their first stages corresponding to the neutralization of strong acids terminate with 0·5 equivalent of an acid, i.e. when $Na_2O,(MoO_3)_4$ and $Na_2O,(WO_3)_4$ are respectively formed. The broken line shows the immediate effect of alkali on the tetratungstate, which is decomposed only after prolonged standing, or on boiling after each addition of alkali, when it is converted into Na_2WO_4 as shown by the curve. The tetramolybdate is converted by alkali immediately into Na_2MoO_4; (3) vanadic acid is initially abnormal. The neutralization of its strong acid stage terminates with the formation of $2Na_2O,5V_2O_5$, which salt is not readily decomposed by the further addition of alkali (hence the broken line in figure 9) except slowly on standing or rapidly on boiling, when the *p*H is shown by the neutralization curve, and the acid then becomes comparable with phosphoric acid in forming the salts Na_2O,V_2O_5 or NaH_2VO_4 and $2Na_2O,V_2O_5$ or Na_3HVO_4.

Electrometric *p*H methods have also been used in several other investigations, many of which await publication.

The Chinese beginnings of alchemy

TENNEY L. DAVIS

It is sometimes stated that alchemy is the parent of chemistry, but in fact alchemy—the attempt to discover an elixir of life and the philosopher's stone—presupposes the accumulation of much chemical knowledge. Professor Davis discusses early Chinese alchemy and suggests that occidental adepts received much of their lore from China by way of India and Islam. The oldest known treatise on alchemy (about A.D. 120) is Chinese.

The beginnings of chemistry are so remote that it is impossible to assign a date to them. They lie in the time which preceded the age of fable and mythology, in that vague and lengthy age during which giants and legendary heroes had not yet appeared, and the pagan gods had not yet discovered their proper ranks and offices. Chemists were already practising their art before the strong god Thor had received his hammer or had hurled his first thunderbolt. Wishing for a weapon, Thor had applied to the dwarfs, to the little metallurgical chemists who stoked their fires under the earth, and had asked them to make him one. Then impatiently he pestered them, until they removed the hammer too soon from the furnace, excellent in all respects except that its handle was unduly short. With a short-handled hammer he accordingly fulfilled his godly functions. When he shook it about his head, the thunder rolled. When he threw it at an object, the object was struck by lightning. Tubal-cain, seven generations removed from Adam, was likewise a chemist, as was his Graeco-Roman counterpart, Hephaistos–Vulcan, who tended his forges under Etna. For the present purpose it is enough to note that no date can be assigned to Tubal-cain or to the dwarfs who worked for Thor, and it is enough to believe that these early chemists, observing the changes which occurred in their processes, undoubtedly had theories—chemical theories—to account for them.

The case is different with alchemy. The term 'alchemy' is understood to signify the search or the effort, whether successful or not, by chemical means to prepare a medicine of longevity or of immortality, or by chemical means to prepare authentic noble metal from base metal—either or both of these pursuits. It follows that alchemy is not as ancient as chemistry, that alchemy arose after the chemical means for its practice had already been developed. Evidently, too, it arose at a time when chemistry has accomplished such marvels that the objectives of alchemy seemed not so extravagant as to be beyond hope of attainment.

Alchemy first made its appearance in such manner that its relation to magic was demonstrated clearly. Gold was wanted because of its magical property of conferring immortality by eating it or by eating out of vessels which were made from it, and chemistry was called upon to make the gold. Chemistry became alchemy when it served for this purpose, and chemical theory, invoked for the explanation of the gold-maker's art, became the theory of alchemy.

The earliest known case of indubitable alchemy is mentioned in the *Shih Chi* [Historical Memoirs] which was commenced by Ssŭ-Ma T'an and completed by his son, Ssŭ-Ma Ch'ien (145-87 B.C.), who succeeded him as grand astrologer and grand annalist to the Chinese court. This work deals with the history of China from the earliest times to 122 B.C. Chapter XXVII tells about Li Shao Chün, a magician and alchemist at the court of the Han Emperor, Wu Ti (156–87 B.C.), within the lifetime of the historian himself, who

> constantly affirmed that he was 70 years of age, that he was able to rule over spiritual matters, and that he could escape old age. . . . He travelled about in order that reports of his prowess might reach the ears of nobility. . . . He excelled in showing himself shrewd, and in saying things at the same time astounding and accurate.

He proclaimed his powers as follows:

> 'I know how cinnabar transforms its nature and passes into yellow gold. I can rein the flying dragon and visit the extremities of the earth. I can bestride the hoary crane and soar above the nine degrees of heaven.'

He offered instruction to the Emperor:

> 'If you will make sacrifice to the furnace, you will be able to transmute cinnabar into gold. When the gold shall have been produced, you may make

of it utensils for eating and drinking. Through using them your life will be prolonged, so that you may see the blessed immortals of the island of P'êng-lai which lies in the midst of the ocean. When you shall have seen them, and shall have made proper sacrifice to high heaven and broad earth, then you will never die.'

The *Shih Chi* further records that

it was after this discourse that the Son of Heaven for the first time performed in person the sacrifice of the furnace. . . . He occupied himself in experimenting with powdered cinnabar, and all sorts of drugs, in order that he might obtain gold.

The Emperor engaged in chemical experimentation from an alchemical motive, hoping to benefit by the magical properties of his product.

An earlier case of what was probably alchemy, although the evidence is not quite so unequivocal, is described in Chapter VI of the *Shih Chi*, which tells of the three supernatural islands in the midst of the Eastern Sea, P'êng-lai, Fang-chung, and Ying-chou: 'It is there that the immortals may be found and the drug which prevents death.' The Ch'in Emperor, Shih Huang Ti (259–210 B.C., King of Ch'in from 246 B.C., Emperor of China from 221 B.C.), the same who established a new dynasty, built the Great Wall, and introduced the hair pencil or brush for writing on silk instead of on bamboo tablets, became interested in what he heard concerning the drug which prevents death. The magicians, Lu Shêng and Hsü Shih, otherwise Hsü Fu, influenced him to organize an elaborate naval expedition for the purpose of searching for them:

Hsü Shih and his companions tendered the following request: 'We make supplication that we be permitted, after we have purified ourselves, to depart with a company of youths and maidens to seek these islands.' . . . The Emperor was well pleased. He gave to Hsü Shih seeds of the five grains and dispatched him upon his voyage with three thousand young men and women, and labourers for all kinds of work. Hsü sailed away, and discovered a locality noted for its peace and fertility. There he tarried, was made king, and did not return.

The Emperor continued to hope for the return of the expedition:

It was his custom to promenade up and down the seashore in the hope that he might in some manner obtain the wonder-working drug of the three sacred islands in the midst of the sea, but he never obtained it. He returned to Sha Ch'iu, and there he died.

The expedition of Hsü Shih set out in the year 219 B.C., and, according to present belief, went to Japan, where it established a settlement near the site of the present city of Shingu, at the eastern end of Wakayama Prefecture, near the southernmost end of the Japanese main island. The grave of Hsü Shih (Joshi or Jofuku, as the Japanese call him) exists at that place and is today an object of reverence by pilgrims and others. Hsü Shih has the reputation of an alchemist, but it has not been definitely established that the medicine which he sought required a chemical preparation and that he was a worker with the processes of chemistry.

Liu An or Huai-nan-tzŭ (died 122 B.C.) was the grandson of the first Han Emperor, Kao Ti, and was created Prince of Huai-nan. He was a famous Taoist and is supposed to have been devoted to the study of alchemy and the search for the pill of immortality, on which subjects he is said to have written several treatises. Wei Po-yang, 'the father of alchemy,' mentions him twice in the *Ts'an T'ung Ch'i* (written about A.D. 142), and Ko Hung (A.D. 281–361), in his chapter on the Yellow and the White, the sixteenth of the Inner Chapters of Pao-p'u-tzŭ, mentions a work of Huai-nan-tzŭ which is not now known to exist, the *Chên Chung Hung Pao* [The Great Treasure in the Pillow Chest], and tells a story from it about a successful transmutation. The only existing writing which bears his name is the *Hung lieh* [Great Light, i.e. *Tao*], a collection of twenty-one essays, probably written by eight famous scholars whom he attracted to his court, or written in collaboration with them, and edited by Huai-nan-tzŭ himself. It is a treatise on cosmogony and ethics, on social problems, on man's place in nature, on the full life. It contains no alchemy, but it does set forth the dualistic *Yin-Yang* doctrine, which supplied a basis for Chinese alchemical theory, for an alchemical theory which was earlier than that of Europe and identical with it in all important respects.

The tradition that Liu An was an alchemist is illustrated by the fact that an account of him is included in the *Lieh Hsien Ch'üan chuan* [Complete Biographies of the Immortals], which tells how he prepared the medicine by chemical means and secured immortality, ascending directly to heaven, by the use of it. Actually he became involved in a political intrigue and, according to one account, was sent into exile; according to another he killed himself. The eight scholars who collaborated with him in his studies are represented in the *Lieh Hsien Ch'üan chuan* as eight

hsien (supernatural immortals), who came to his court for the purpose of instructing him concerning *Tao*. One of them, the last to speak in the passage quoted below, was obviously a chemist:

'We have heard that your Highness loves the *Tao*. So we have come to join your court. But we do not know what your Highness desires.

'One of us can cause winds and rain by sitting down, can raise clouds and fog by standing up, can make rivers and lakes by drawing on the ground, and can create mountains by piling of sand.

'One of us can crumble heights and fill up the deep, can husband the tiger and the leopard, can catch the dragon and the snake, and can master gods and ghosts.

'One of us can separate his form and change his appearance, can cause life by sitting down and death by standing up, can cover a complete army from sight, and can turn broad daylight into darkness.

'One of us can ride in space and walk on emptiness, can go into the sea and the deep, can go in and out through any partitions, and can breathe a breath of a thousand miles.

'One of us can go into the fire without being scorched, and into water without being wetted, can be stabbed without being hurt, can be aimed at but never hit by an arrow, and is not cold in freezing water, and does not sweat in summer.

'One of us can perform thousands of changes at will. He can bring forth birds and animals, weeds and woods in a moment. He can move mountains, heights, and rivers.

'One of us can prevent havocs, reclaim from dangers, dispel evils, and do away with harmful things. He can cause longevity.

'One of us can boil mud to get gold, assay lead to get silver, and treat the eight stones to give pearls. He can ride the dragon and harness the clouds to travel afloat on the Great Clearness.

'What does your Highness desire?'

Liu An made obeisance to the eight *hsien*. He offered wines and fruits to them with his own hands. The *hsien* were tested one after the other and were confirmed in their ability. He was given the Book of the Medicine, the Thirty-Six, and the mercury recipes. The medicine was made but was not taken.

Now Liu An had a son, of the name of Ch'ien, who loved fencing. One day Ch'ien fenced with an official and was hurt. The latter, fearing punishment, wrote to the Emperor alleging that Liu An was plotting revolt. The Emperor sent Tsung Chêng to bring Liu An to justice.

The eight *hsien* said to Liu An: 'You must go now. This is a heaven-sent messenger for you to depart. So harbour no doubt.' Liu An went with them up into the mountain. There they made a great ceremonial offering and buried the gold in the earth. They rose to the sky in broad daylight.

The stones on which the eight *hsien* and Liu An had stepped became marked. Even now they are found to have the footprints of men and of horses. Chickens which peck at the *tings* [furnace-pots, three-legged incense-burners] used in preparing the medicine, and dogs which lick them, attain lightness. The chickens will cackle and the dogs will bark in the sky.

The dualistic doctrine of Yin-Yang appeared in China during the third century B.C., and from that time to this has dominated a large part of Chinese thought on philosophical and scientific matters. Similar doctrines existed in other places at an earlier date, notably in India and in Mesopotamia, and it is possible that they may have been imported into China. In any case, it is interesting to find that the doctrine appears already elaborated, already supplied with an extensive and fantastic symbolism, at the moment when it first occurs in association with alchemy, in the earliest known treatise in any language which is devoted exclusively to that subject.

The earliest known treatise on alchemy is the *Ts'an T'ung Ch'i* [Akinness of the Trio] of Wei Po-yang. It has been preserved for us as part of the Taoist canon. Its author, about whom very little is known, was a native of Wu in the present province of Kiangsu. In the year A.D. 121 he was summoned to court, but refused the invitation because he had no liking for officialdom. An account of him, containing elements which are obviously mythical, is found in the *Lieh Hsien Ch'üan chuan*. In the Epilogue of the *Ts'an T'ung Ch'i* he describes himself as 'a lowly man from the country of Kuai who has no love for worldly power, glory, fame, or gains, who wastes his days leading a simple, quiet, leisurely, and peaceful life in a retreat in an unfrequented valley.'

Primitive science viewed all things as resulting from the combination or interaction of the Two Contrary Principles, one of them having all of the positive qualities, active, hot, dry, light, and spiritual; the other, all of the negative qualities, passive, cold, wet, heavy, and material. Since the Contraries were difficult to describe precisely, they were designated by names which had broad connotations; they were associated with deities, Osiris and Isis, Baal (or Bel), and Astarte (Ashtaroth or Ishtar), Shiva and Parvati; with the two regulating powers of the universe, one of them, *Yang*, the principle of activity, the other, *Yin*, the principle of material acted upon. They

FIGURE 1 – *Liu An, Prince of Huai-nan.*
Liu An and one of the *hsien* who taught him the art. The dog and the cock, having respectively licked and pecked at the vessels in which the medicine was made, also ascended into the sky.
(*Reproduced from the* Lieh Hsien Ch'üan chuan [*Complete Biographies of the Immortals*].)

FIGURE 2 – *The preparation of the pill of immortality according to Shang-yang-tzu.*
Yang is represented by the man, dragon, and fire; *Yin* by the woman, tiger, and water in the forms of clouds, rain, and hail. The tortoise and the serpent, symbolizing the material embodiments of *Yang* and *Yin*, further represent the combination of the Two Contraries.
(*Reproduced from the Ming edition of the* Chin Tan Ta Yao [*Essentials of the Gold Medicine*], *written by Shang-yang-tzu, otherwise Ch'ên Kuan-wu, during the Chih-shun reign of the Yuan dynasty* (A.D. 1330–33).)

were designated by names which are to be taken as symbols suggestive of all of the qualities which each of them possessed. In Europe and in China alike they were Sun and Moon, Man and Woman, Fire and Water, Hot and Cold, Volatile and Fixed. For the Alexandrian chemists, and for the later European chemists and alchemists, the metals were combinations of the positive Sulphur and the negative Mercury principles, gold being the perfect combination of the two, and the principles being bundles of qualities, not confounded with yellow brimstone and liquid quicksilver. For the Chinese alchemists, positive *Yang* was Lead (instead of Sulphur), Dragon, the Golden Crow; negative *Yin* was Mercury, Tiger, the Jade Rabbit, and so forth. The same Two Contraries were known as Phlogiston and Calx to the chemists of the eighteenth century.

The *Ts'an T'ung Ch'i* describes the preparation of the pill of immortality by the heating together of the Two Principles in a closed vessel from which no vapours can escape, at first gently and finally with a strong fire. The hermetically sealed vessel, which the later European alchemists

FIGURE 3 – *The Combination of the Two Principles for the Production of the Philosopher's Stone.*

The intent of this picture is strikingly similar to that of figure 2. The Sulphur principle is represented by the Sun, by the King, and by fire; the Mercury principle by the Moon, by the Queen, and by water. [Note that the clouds above the Queen are not radiant as are those above the King.]

FIGURE 4 – *An alchemist's laboratory according to Basil Valentine.*

Obviously a place for the combination of the two contrary principles.

(Reproduced from wood-cut in the third German edition [Hamburg, 1700] of Basil Valentine's collected chemical writings.)

denominated the 'Philosopher's Egg,' is described by Wei Po-yang:

> On the sides there is the walled enclosure, shaped like a *p'eng-hu* pot. Closed in all sides, its interior is made up of intercommunicating labyrinths. The protection is so complete as to turn back all that is devilish and undesirable, and the meandering passages take good care of emergencies.

The tortuous passages serve as reflux condensers for the return of volatile material. The Principles themselves are indicated by allegorical names.

> In order that the Treatise on Fire shall not have been in vain, I shall explain here in simple language. Like the moon lying on its back is the shape of the furnace and the pot. In it is heated the White Tiger. Mercury Sun is the flowing pearl and with it is the Blue Dragon. The east and west merge together, and so the *hun* and *p'o* control one another. . . . The Red Bird is the spirit of fire and dispenses victory or defeat with justice. With the ascendance of water comes the vanquishing of fire.

The process itself:

> Treatment and mixing will bring about combination and rapid entrance to the scarlet portal. The escape must be firmly blocked. Below plays the dazzling flame, while the Dragon and Tiger keep up a sustained vociferation. The flame at the start should be weak, so as to be controllable, and should be made strong at the end. Close attention and careful watch should be given so as to regulate properly the heat and the cold. . . . The colour changes into a purple. Behold! the Returned Medicine is obtained. This is then made into pills. These are extremely efficacious, although their individual size is so small that they occupy only the point of a knife or the edge of a spatula.

Wei Po-yang describes the appearance of the materials in language which indicates that he had observed chemical phenomena and had been profoundly impressed by them. There can be no doubt that the following passage is a description of a violent reaction accompanied by colour changes and the production of a sublimate:

> Above, cooking and distillation take place in the cauldron; below blazes the roaring fire. Afore goes the White Tiger leading the way; following comes the Grey Dragon. The fluttering Scarlet Bird flies the five colours. Encountering ensnaring nets, it is helplessly and immovably pressed down and cries with pathos like a child after its mother. Willy-nilly it is put into the cauldron of hot fluid to the detriment of its feathers. Before half of the time has passed, Dragons appear with rapidity and in great number. The five dazzling colours change incessantly. Turbulently boils the fluid in the furnace. One after another they appear to form an array as irregular as a dog's teeth. Stalagmites, which are like midwinter icicles, are spit out horizontally and vertically. Rocky heights of no apparent regularity make their appearance, supporting one another. When *Yin* and *Yang* are properly matched, tranquillity prevails.

It is difficult not to believe in the continuity of alchemical thought when we find the same process described in the *Speculum alchemiae* which is ascribed to Roger Bacon, a treatise written more than a thousand years later than the *Ts'an T'ung Ch'i:*

> Another says: 'This work is similar in many respects to the creation of man, for, as a child is nourished at first with lighter foods until the bones are formed, then with stronger ones, so this magistery requires a slow fire by which it is acted upon in the manner of a decoction.' And always when we speak of a slow fire, we mean that the fire is to be augmented and made stronger gradually and in successive stages during the course of the work. . . .
>
> If, then, we intend to imitate nature, we must necessarily have a furnace of the same sort, after the fashion of a mountain, not in size, but of such sort as to provide a continuous heat so that the fire imposed upon it shall not find an exit when it ascends and so that the heat shall reverberate the tightly closed vessel which contains within itself the material of the Stone. . . .
>
> And as in the mines the heat does not touch directly the substance of the Sulphur and of the Quicksilver, because the earth of the mountain is everywhere between, so the fire ought not to touch directly the vessel which contains the above-mentioned materials. But this vessel must be placed within another vessel similarly closed, so that a temperate heat may better and more aptly reach the material above and below and from whatever side it may be.

Persons who ate the pill of immortality became *hsien*, supernatural immortals, for ever young, able to travel great distances, to pass through fire without being burned, through water without being wetted, able to change their form, to appear and to disappear at will. The powers of a *hsien* were the powers of a *jinn* as described in *The Arabian Nights Entertainments*, suggesting that the Arabic word may perhaps be derived from the Chinese and indicating a possible line of transmission whereby alchemy came from China to Europe.

The Latins received their alchemy from the Arab writers, who, though they may perhaps have received some of their chemistry from the Alexandrians, certainly received no alchemy from that source—for the Alexandrians had no alchemy to transmit. The Alexandrians had a dualistic chemical theory; they were interested in colour, and they applied their chemistry among various ways to the imitation of the noble metals. But they knew full well that their yellow and white metals were not genuine gold and silver. The Arabs had chemistry and they understood the art of colouring the metals; but they also had real alchemy, which they probably received from China, and they hoped to prepare authentic gold and silver by chemical means.

The truly alchemical character of Ko Hung's teaching is evident from the following remarkable passages, quoted from his chapter on the Yellow and the White, which show that he understood the art of imitating the metals and distinguished it clearly from genuine transmutation:

> It is another story with the *chên jên* [men of truth, men proficient in the art, sages]. For they make gold with the purpose, not of getting rich, but of

becoming *hsien* by eating it. Therefore it is written in the book: 'Gold can be made wherewith people can be raised above this worldly life.' Silver may be eaten for similar ends but is not as effective as gold.

Then I asked further: 'Why should we not eat the gold and silver which are already in existence instead of taking the trouble to make them? What are made will not be real gold and silver but just make-believes.'

Said Chêng Chün in reply: 'The gold and silver which are found in the world are suitable for the purpose. But *Tao-shih* [seekers of the Way] are all poor; witness the adage that *hsien* are never stout and *Tao-shih* never rich. *Tao-shih* usually go in groups of five or ten, counting the teacher and his disciples. Poor as they are, how can they be expected to get the necessary gold and silver? Furthermore, they cannot cover the great distances to gather the gold and silver which occur in nature. The only thing left for them to do is to make the metals themselves.

'In that they are the essences of the medicines, the gold and silver made are superior to those found in nature. . . .

'The gold obtained by successful compounding is uniform inside and out. It may be put through a hundred workings without suffering any change. Therefore it is written in the formulas for its making that it may be made into nails. That shows its strength. Such results come of responsive infusion of the *Tao* of nature. Why should such deeds be called make-believes?

'Make-believes should be like the besmearing of iron with *ts'êng ch'ing* [malachite], whereby the metal takes on a reddish sheen simulating copper, and the action of egg-white on silver to obtain a yellow colouring resembling gold. In all these cases there are merely external changes but no internal transmutations.

'The fungus *chih* [plant of longevity] is a natural growth. But according to the *Hsien Ching* [Book of Immortals] it may be cultivated by means of the five stones and the five plants. The resulting plant will be exactly like that found in nature in the power of giving long life when eaten. The case is similar to the making of gold[1].

[1]While the translations quoted in the present paper are due mainly to the late Wu Lu-ch'iang, many of the facts and conclusions are due to my other Chinese collaborators or to discussions with them. This paper, embodying material from several earlier ones, would not have been possible without the past collaboration of Ou Chia-wei, Ma Chuk-ching, Su Gouq-jen, Chao Yün-ts'ung, and Ch'ên Kuo-fu. T.L.D.

Book reviews

ORGANIC CHEMISTRY

Theoretical Organic Chemistry, *by J. B. Cohen. Revised edition by P. C. Austin. Pp. xv* + 622. *Macmillan & Co. Limited, London.* 1942. 10*s. net.*

The fundamental character of developments in organic chemistry arising from the growth of modern electronic theory necessitates very extensive revision of any older textbook if a really modern work is to result.

In this revised edition of the late Professor Cohen's well-known book the general plan and text of the original have been very largely preserved. A new chapter on stereochemistry has been added, the sections on carbohydrates and proteins have been modernized, and heterocyclic compounds, alkaloids, ureides, and compounds of biological importance have been grouped together into a third, new, section. Such revision is adequate, but it is unfortunate that equal thoroughness is not evident throughout. Thus, as examples, although a short chapter outlining the electronic character of covalent, electrovalent, and co-ordinate links has been included, formulae containing quinquecovalent nitrogen are generally unchanged. Obsolete potash bulbs are still the only absorbent given for carbon dioxide in analysis. Claisen's original mechanism for the Claisen condensation (p. 328) and Fittig's for the Perkin reaction (p. 501), both now completely discredited, are reproduced unchanged. Diamines, choline, neurine, and taurine have, with advantage, been transferred to Chapter XIV on Amines, but still appear in Chapter XIX (Polyhydric Alcohols) in the unrevised Contents page xi. The statement that 'no completely satisfactory solution has yet been found' for the structure of benzene (p. 383) and for orientation rules in benzene substitution (p. 483) hardly gives the student a fair picture of the success of the resonance theory in interpreting the chemical and spectroscopic properties of benzene, or of electronic theories in the interpretation of aromatic substitution.

Notwithstanding such deficiencies, its amazingly comprehensive factual content makes the textbook a most valuable one for students and exceedingly good value at the price charged. J.W.B.

VITAMIN CHEMISTRY

Chemistry and Physiology of the Vitamins, *by H. R. Rosenberg. Pp. xx* + 675. *Interscience Publishers Inc., New York; Imperia Book Company Limited, London.* 1942. $12.00.

This book is outstanding in that it covers the field of chemistry and biochemistry of vitamins exceptionally well and ably describes the remarkable advances achieved in this connection during the past twenty years. The physiological aspect of the subject, which demands a wide knowledge of physiology, pathology, and medicine, is not, however, so well treated. This is a pity, since physiological investigations on vitamins have had a greater influence on the subject of physiology

than the parallel chemical investigations have had on pure chemistry. Whereas chemical and biochemical discoveries are fully surveyed, biological discoveries, even of a revolutionary nature, are often mentioned only casually, with little or no appreciation of their significance. Occasionally important and unimportant facts and claims are confused. This lack of critical appreciation detracts from the book's value to physiologists and may be misleading to those whose acquaintance with the subject is limited.

The book is very well produced and contains useful (although on the physiological side non-selective) indexes, including a patents index. From an educational standpoint, and for purposes of reference to the chemical aspect of vitamin research, it deserves the highest praise and recommendation. It might, however, be suggested that in the next edition the author should change the title to 'The Chemistry and Biochemistry of Vitamins.'

RECENT WORK ON COLLOIDS

Advances in Colloid Science, *edited by E. O. Kraemer, F. E. Bartell, and S. S. Kistler. Pp. xii + 434. Interscience Publishers Inc., New York; Imperia Book Company Limited, London,* 1942. 33*s. net.*

This volume contains twelve articles, most of them by first-rate experts, on many topics of current interest; only some can be mentioned here. T. F. Anderson describes the theory and many applications of the electron microscope very clearly, and gives many excellent photographs. R. J. Myers gives an excellent account of the interchange of ions between aqueous solutions and synthetic resins of carefully chosen constitution, on which an important new process for water purification is based. Emmett reviews in detail the way in which the amount of gas adsorbed depends on pressure, in cases where fairly large amounts are adsorbed, largely, if not entirely, by van der Waals forces, and convincingly works out a method for determining when the adsorbed layer is one molecule thick. From this, the total surface of the solid can be deduced. McBain collects a number of not very well known facts bearing on the way in which aqueous solutions of colloids, such as soap or similar substances, dissolve quite large quantities of substances which have very slight solubility in water alone, and discusses their importance for detergent action and for the permeability of membranes. Edsall's article on double refraction in solutions of minute, elongated particles, developed only when the solution flows under conditions involving shear, is masterly; so is Kurt Meyer's on starch. Powell and Eyring's treatment of viscosity, diffusion, and some other properties of solutions of large molecules is somewhat speculative, but full of new and stimulating ideas. Hauser gives a new method, based on measurement of the shape of hanging drops, for finding surface tension; but his discussion of 'anomalies' in surface tension is rather misleading, for he falls into the rather common error of trying to fit the simplified form of Gibbs' adsorption equation, which is really applicable only to two-component systems, to data obtained on solutions which must have at least three components where surface equilibria are involved.

This volume is indispensable to serious students of colloidal materials and should be in every library dealing with physical chemistry. It is all interesting, and most of it is of great importance. N. K. ADAM

THE THEORY OF VOLUMETRIC ANALYSIS

Volumetric Analysis, *by I. M. Kolthoff and V. A. Stenger.* Volume I: Theoretical Principles. *Pp. xv* + 309. *Interscience Publishers Inc., New York; Imperia Book Company Limited, London. Second revised edition.* 1942. 30*s. net.*

The first edition of this work, published in German in 1927 and translated into English by Professor N. H. Furman in 1928, filled an important gap in the literature of volumetric analysis and stimulated a greater interest in the study of the theory of the subject. This has been reflected in the space devoted to theoretical principles in a number of well-known and reasonably priced textbooks of quantitative inorganic analysis, including that of Kolthoff and Sandell (1936). About half the matter in the book under review is adequately covered by these textbooks, and it would appear to be an open question whether the remaining subject-matter justifies the publication of an independent volume at a price which is very high. In the reviewer's opinion, it would have been far better to combine Volume I with the promised new edition of Volume II (dealing with the practical side).

The book appears to be somewhat unbalanced. Thus in the chapter on indicators ten pages are devoted to acid-base indicators, but neither their structures nor the theories of the colour changes are discussed; on the other hand, thirty-five pages, including many detailed structural formulae, are given to oxidation-reduction indicators. The treatment is in some cases not always up to date, particularly in the otherwise interesting chapter on volumetric methods of organic analysis; here the reactions of unsaturated compounds are discussed from the viewpoint of Thiele's partial valency theory.

In spite of the above criticisms, the volume contains much of value to those interested in volumetric methods of analysis. Many references to the literature are provided. A. I. VOGEL

A DICTIONARY OF SCIENTIFIC TERMS

A Dictionary of Science, *by E. B. Uvarov, B.Sc. Penguin Books Limited, London and New York.* 1943. 9*d. net.*

This dictionary, compiled by a competent scientific lecturer, has been specially designed to help all those studying, or interested in, science. The majority of its definitions apply to physics, chemistry, and mathematics; the many cross-references will prove most helpful to readers. The suggestion might be ventured that in a later edition certain terms, for instance alembic, alkahest, astrolabe, and phlogiston, should give way to modern ones such as electron-volt, photoelectron, the Compton and Raman effects, etc. This, however, is a minor point and purchasers of this compact little volume will find they have got excellent value for their money.

C. M. BEADNELL

A TEXTBOOK FOR ENGINEERS

Modern Engineering, *by C. H. S. Tupholme. Pp. xi* + 201. *Faber and Faber Limited, London.* 1942. 15*s. net.*

The author of this book attacked a very wide subject in a definite manner and has achieved considerable success. Modern engineering is linked so closely with other sciences, such as physics and chemistry, and recent progress has been so rapid, that exhaustive treatment became neither possible nor desirable in a book such as the one under review. Accordingly, the author adopted the

method of presenting details of various important developments which have proved commercially successful. He has not attempted theoretical discussion, but has borne in mind the needs of younger men about to embark upon an engineering career, although the book is by no means limited to such requirements.

It is generally recognized that wartime conditions accelerate the rate of scientific and technical advance, while attempts at self-sufficiency stimulate inventive effort, and this viewpoint has been emphasized by Mr Tupholme; for example, if one turns to the question of mechanical power, details of the Velox steam generator, the Sulzer monotube boiler and the mercury vapour system will be found. In the case of engineering workshop processes there are excellent descriptions and explanations of many and diverse methods by which accuracy within very fine limits is obtainable.

The chapters on air-conditioning, refrigeration, chemical engineering, metallurgy, electrical and marine engineering, and traction are equally well treated. The section on aircraft will undoubtedly have a great appeal because in it many of the latest developments are dealt with, while the concluding chapter consists of brief descriptions of some recent advances in physics.

Particular mention must be made of the very excellent illustrations, twenty-three of which are full-page half-tone plates. The book is well written and produced and should have a wide appeal. ARTHUR MARSDEN

X-RAY INVESTIGATION OF TEXTILES

Textile Fibres under the X-rays, *by W. T. Astbury. Pp.* 53, *with* 34 *figures. Imperial Chemical Industries Limited, London.* 1942. *N.p.*

This book is an album of X-ray diffraction photographs of textile fibres, with notes on each photograph, and an introduction describing the apparatus used in taking the photographs and the conclusions which can be drawn from them. Great care has been taken to display Astbury's excellent photographs to the best advantage, and the result is very pleasing to the eye as well as uncommonly informative. The text, written in a very attractive style (Astbury is a master of simple exposition), tells the layman what X-ray analysis is all about, and gives a bird's-eye view of the contributions it has made to our knowledge of the molecular structure of textile fibres.

C. W. BUNN

INDUSTRIAL TYPES OF CATHODE RAY OSCILLOGRAPHS

The Cathode Ray Oscillograph in Industry, *by W. Wilson. Pp. xii* + 150. *Chapman & Hall Limited, London.* 1943. 12*s.* 6*d.* net.

This entirely practical and very useful book is well designed to meet the great and growing demand for detailed information on industrial types of cathode ray oscillographs, both glass and metal. As it is intended for the actual user rather than for the academic reader, historical matter and mathematical treatment are almost entirely omitted to provide the maximum space for descriptions of apparatus and components, practical tests, and industrial applications. Television tubes are excluded, but electron diffraction apparatus and the electron microscope are described, and an appendix deals briefly with thermionic valves, photo cells, oscillators, and piezo crystals. Many well-reproduced photographs of apparatus and components and of oscillograms are included, as well as electrical circuit and other line diagrams. W.J.

THE ESSENTIALS OF ENTOMOLOGY

Outlines of Entomology, *by A. D. Imms. Pp. viii* + 184, *with* 96 *illustrations. Methuen & Co. Limited, London.* 1942. 12*s.* 6*d.* net.

This is a masterly presentation of the essentials of entomology. It has been written with a selectivity arising from a marriage of ripe experience with great knowledge. It presents lucidly and attractively the facts needed for an elementary appreciation of the anatomy, physiology, and classification of insects, and of their place in evolution. The interest thus aroused will be stimulated by the admirable little essays on general subjects, which spring most naturally out of relevant sections and lead the inquiring mind towards the more fascinating problems of insect behaviour. The index is adequate, and paper and illustrations are excellent.

H.N.

WIRELESS RECEIVERS

Radio Receiver Design. Part I: Radio Frequency, Amplification, and Detection, *by K. R. Sturley. Pp. xii* + 435. *Chapman & Hall Limited, London.* 1943. 28*s. net.*

Dr Sturley's book forms a useful collection of the principles involved in radio frequency amplification and detection. Its name is somewhat misleading since, apart from a few charts, there is no emphasis on practical design details. This is noticeable when mathematical conclusions are left with scant mention of the implications. It is, on the other hand, a most valuable introduction to the subject for those interested in broadcast and communication receivers. S.J.

EVOLUTION AND MORALITY

Science and Ethics, *by C. H. Waddington and others. Pp.* 144. *George Allen and Unwin Limited, London.* 1942. 7*s.* 6*d. net.*

Some time ago Dr Waddington wrote an article in *Nature* on "The relations between science and ethics" which led to a considerable discussion, and is reprinted here with comments from many sources. His thesis is, that the evolutionary process supplies us with a criterion of good, and that we need no other basis for morality. In some ways it reminds us of the Stoic doctrine of Deity evolving itself.

As the commentators point out, there seem to be discrepancies between the theory and the facts. Thus slavery, which was unknown among the earlier types of mankind, became universal in the civilizations of the ancient world; and therefore, according to Dr Waddington's criterion, slavery, being a principle developed by social evolution over a vast stretch of time, must be pronounced good. The Christian ethic, which frowned on slavery and eventually succeeded in abolishing it, was in fact completely opposed to the direction of the antecedent evolutionary process.

Much of the work of Dr Waddington and his critics reaches a high level and makes interesting reading; but one can imagine Burke saying, as he did of a similar attempt long ago, that he was 'not more than transiently amused with paradoxical morality.' E.T.W.

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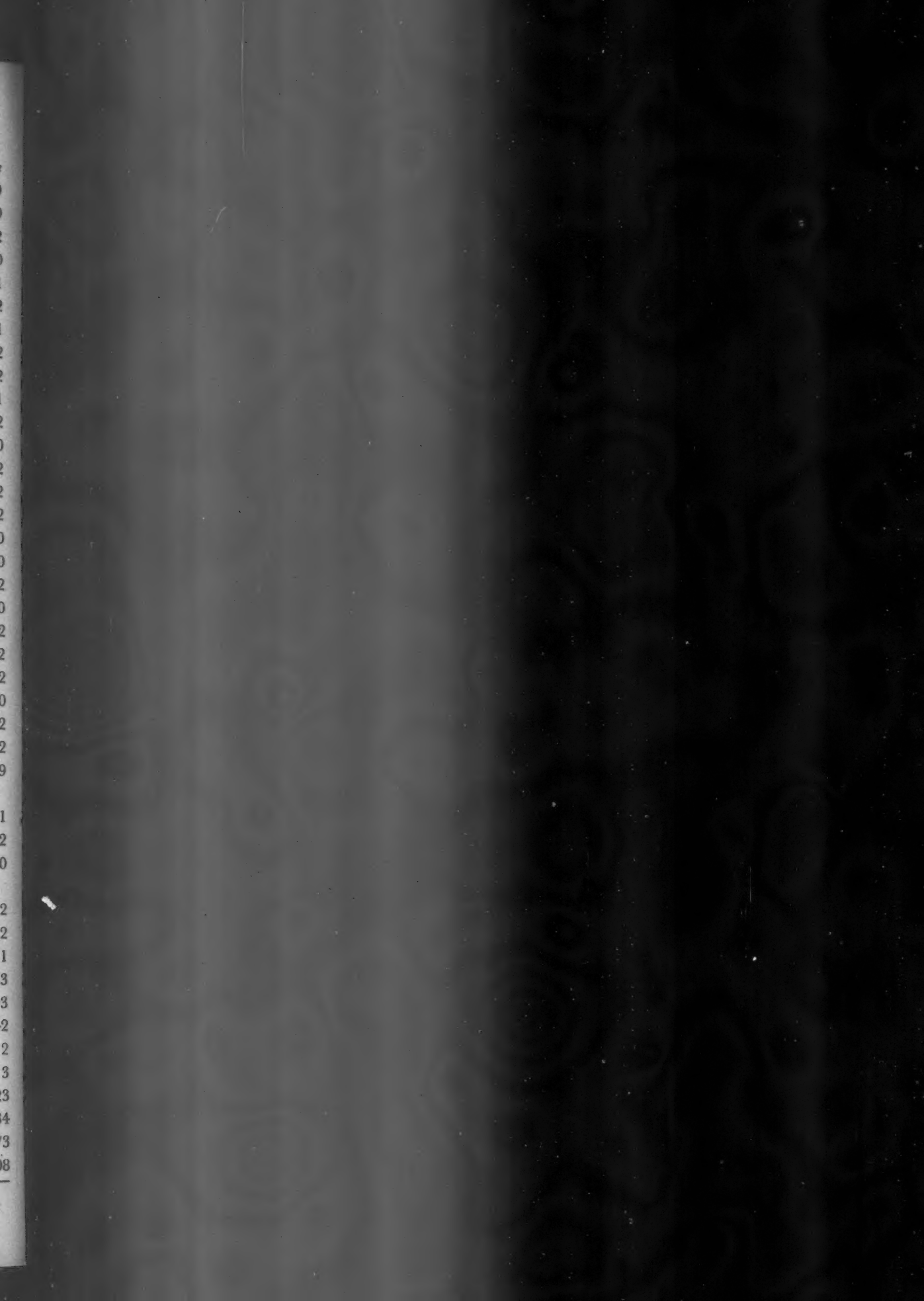

Notes on contributors

SIR GEORGE PAGET THOMSON, *M.A., Sc.D., Hon. D.Sc. (Lisbon), F.R.S.*,

Is the only son of the late Sir J. J. Thomson (formerly Cavendish Professor of Physics, then Master of Trinity College, Cambridge, and Nobel Laureate, 1906) and of Lady Thomson, daughter of the late Sir George Paget, Regius Professor of Medicine at Cambridge. He was educated at the Perse School and at Trinity College, Cambridge, where he took first-class honours in the mathematical and natural sciences triposes.

In the year 1914 he was appointed to a Fellowship and as a Lecturer at Corpus Christi College, Cambridge, but on the outbreak of war in that year he received a commission in the Queen's Regiment and served in France. He was later attached to the Royal Air Force for experimental work, and in 1918 went to the U.S.A. as a member of the British War Mission. At the end of the war he wrote *Applied Aerodynamics* and, returning to Cambridge, carried out various researches at the Cavendish Laboratory.

In the year 1923 he was appointed to the Professorship of Natural Philosophy in the University of Aberdeen, and it was there that he carried out his work on the diffraction of electrons in crystals which provided a verification of de Broglie's theory of the electron. In 1929 he visited Cornell University, U.S.A., to give the Baker Lectures, and in the following year was appointed Professor of Physics in the University of London. He was awarded the Nobel Prize for Physics in 1937, and the Hughes Medal of the Royal Society in 1939. In 1937 he was appointed by the British Air Ministry to the Advisory Committee for Aeronautics, and since the war has served in the Royal Aircraft Establishment at Farnborough, as Scientific Liaison Officer in Ottawa, and as Deputy Chairman to the Radio Board. He resigned the last post in 1943 and is now working at the University of London. His recreations are ski-ing and sailing.

HERBERT DINGLE, *D.Sc., A.R.C.S.*,

Was born at Brixton, London, in 1890, but spent his early life at Plymouth, where, after leaving school, he was for some years employed by the local Education Authority. In 1915 he entered the Royal College of Science, London, as a student of physics, and after graduating remained at the College as Lecturer, Assistant Professor, and Professor of Natural Philosophy. He is a member of many British and foreign learned societies, and is Vice-president of the Royal Astronomical Society. In 1936 he was Lowell Lecturer at Boston, U.S.A., and in 1927 and 1932 was a member of the British Government Eclipse Expeditions (the 1940 expedition, of which also he was a member, was cancelled). His scientific work has been chiefly concerned with spectroscopy (especially in its applications to astronomy and medical and industrial problems), relativity, and the philosophical aspects of science.

F. E. FRITSCH, *D.Sc. (London), Ph.D. (Munich), F.R.S.*,

Was born in London in 1879 and was educated at Warwick House School, Hampstead, and the Universities of London and Munich. From 1906–11 he was Assistant Professor of Botany at University College, London, and in the latter year was appointed Head of the Department of Botany, Queen Mary College, and Professor of Botany in the University of London. In 1927 he was President of the Botanical Section of the British Association for the Advancement of Science, and in 1932 visited Stanford University, California, U.S.A., as guest professor. For the last fifteen years he has been writing a general treatise on the structure and reproduction of the algae, but since the war has devoted much time to the investigation of the seaweeds causing the fouling of ships, and is a member of the marine corrosion subcommittee of the Iron and Steel Institute which is investigating this matter. He is fond of gardening, and very much interested in chamber music, playing both violin and viola.

H. T. S. BRITTON, *D.Sc., D.I.C., F.I.C.*

Born at Bristol in 1892, he was educated at the St George's and Merchant Venturers' Schools there, and at Bristol University. He then attended King's College and the Royal College of Science, London. During the war of 1914–18 he worked in the Air Ministry Laboratories, afterwards returning to King's College as Assistant Lecturer in Chemistry. In 1928 he became Lecturer in Physical Chemistry at the University College of the South-West, Exeter, where seven years later he succeeded to his present post of Professor of Chemistry. Since 1920 he has carried out numerous researches on the application of physico-chemical methods and principles, particularly *p*H, electrical conductivity, E.M.F., optical activity, and the phase rule. A successful teacher, he is also the author of two standard monographs, *Hydrogen Ions* and *Conductometric Analysis*.

TENNEY L. DAVIS, *B.S. (Massachusetts Institute of Technology), M.S., Ph.D. (Harvard)*,

Was born at Somerville, Mass., U.S.A., on 7th January, 1890. He was Austin Teaching Fellow at Harvard from 1913–16, and Sheldon Travelling Fellow in 1916–17. In 1919 he became Instructor in Organic Chemistry at the Massachusetts Institute of Technology, where he subsequently held the posts of Assistant Professor, Associate Professor (1926), and Professor (1937). He was made Emeritus Professor of Organic Chemistry when he retired from the Institute in 1942, and is now Director of Research and Development of National Fireworks Inc. He is on the editorial board of *Archeion*, the *Journal of Chemical Education*, and *Isis*, and is one of the leading American historians of chemistry. His work on the early history of chemistry in China has thrown much light on chemical origins. Since 1930 he has been one of the secretaries of the American Academy.

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